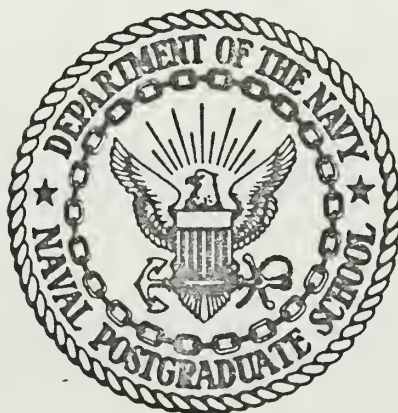


AN INVESTIGATION OF THE ROBUSTNESS
OF "STUDENT'S" T-TEST USING
BETA AND ERLANG DISTRIBUTIONS

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THESIS

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by

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ABSTRACT

The robustness of "Student's" t-test with regard to the assumption of normality is investigated. This is accomplished by empirically developing the distribution of a new statistic from a large number of samples of varying sizes from the Beta and the Gamma distributions using different values of the parameters. The various significance levels of this new distribution are then compared with the corresponding significance levels from "Student's" t distribution using an IBM 360 computer. A comparison of the distribution frequencies with the standard normal distribution frequencies is also presented.

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I. INTRODUCTION

In practical work, an Operations Research Specialist is generally involved with the problems of bringing the theoretical structures into some degree of correspondence with the situations of practical experience. One of the common methods of achieving this objective is by hypothesis testing. The hypothesis testing method makes use of a variety of statistical techniques and procedures involving both parametric and non-parametric tests. In the derivation of most of the parametric tests, it is usual to assume a form of mathematical model involving some specific probability distribution and then to select some statistical criterion that is sensitive to change in the specific factors tested. This type of criterion is generally known as the "power of the test".

However, another desirable requirement of any statistical test is that it be insensitive to change in the underlying assumptions. This property of the test is generally referred to as the "robustness" of the test. Common questions probing into the robustness of a test are: When the actual distribution is not known, which statistical tests can be used with less hesitation?; and What percentage of error would be incurred if the underlying assumptions are violated? Past research and subsequent literature indicate that the property of robustness is generally not satisfied by the parametric tests. This is substantiated by research conducted by G.E.P. Box [7] and R. C. Geary [8].

One of the most common parametric tests used for hypothesis testing is "Student's" t-test. This test was developed by

William Sealy Gosset in 1908 when he was working for Guinness Brewery in Dublin, Ireland. The discovery of the t-test was a direct result of the peculiar problems of brewing with its variable material and its susceptibility to temperature changes. A number of experiments conducted at the brewery emphasized the limitations of large sample theory and revealed the necessity for a correct method of treating small samples. It was, therefore, the circumstances of Gosset's work which led to his discovery of the Theory of Errors and the distribution of the Sample Standard deviation, which was developed later into the well known t-test.

II. "STUDENT'S" t DISTRIBUTION

As was mentioned earlier, the Theory of Errors finds its origin in the fact that the accuracy of the mean of a number of observations may be estimated from the discrepancies observed among the individual values used in obtaining the mean. When the samples are drawn from a normal population, having a variance (mean squared deviation) equal to σ^2 , it can be shown that the mean of N observations \bar{x} is also normally distributed with variance $\sigma_{\bar{x}}^2 = \frac{\sigma^2}{N}$. Thus if the variance of the mean is known, then the desired information regarding the distribution of the mean can be easily determined. In order to test a hypothesis that the population has mean μ , one would merely need to calculate $t = \frac{\bar{x} - \mu}{\sigma/\sqrt{N}}$ and then the integral

$$I = \frac{1}{\sqrt{2\pi}} \int_t^{\infty} e^{-\frac{t^2}{2}} dt$$

would give the probability that a more

discrepant value would occur. If the value of I so calculated turns out to be a small quantity, such as .01, one should conclude with some confidence that the hypothesis was not, in fact, true of the population sampled.

In a majority of the cases in which such tests are required, one can find no prior knowledge of the variance of the population. The variance of the population can be estimated, however, from the sample itself by the following relationships:

If X_1, X_2, \dots, X_N represents a sample; then $s^2 = \frac{1}{N-1} \sum_{i=1}^N (X_i - \bar{x})^2$ is an estimate of the unknown variance σ^2 , and $\bar{x} = \frac{1}{N} \sum_{i=1}^N X_i$ is

the sample mean and an estimate of the population mean.

W. S. Gosset, in his fundamental paper of 1908, showed that even though s as calculated above is a good estimate of σ , it would be erroneous to assume that the statistic $t = \frac{\bar{x} - \mu}{s/\sqrt{N}}$ would be normally distributed or that the significance of an observation could be accurately tested by using the normal probability theory. Assuming the independence of s^2 and \bar{x} , Gosset was able to develop the exact distribution of this statistic, which in its modern form is known as "Student's" t distribution. It states that if X and U are two independently distributed random variables such that X is normally distributed with mean μ and variance σ^2 , and U has chi-square distribution with N degrees of freedom, then the ratio $t = \frac{X - \mu}{\sigma} / \sqrt{U/N}$ has the distribution of "Student's" t , and its density function is given by

$$f(t) = \frac{\Gamma(\frac{N+1}{2})}{\sqrt{\pi N} \Gamma(\frac{N}{2})} \cdot \frac{1}{[1 + \frac{t^2}{N}]^{\frac{N+1}{2}}}, \quad \text{where } -\infty < t < \infty$$

From this definition, it can be seen that "Student's" distribution depends on N only and is independent of both parameters of the normal distribution sampled. It is further noted that the derivation of "Student's" t distribution depends on the fact that the random variable X be drawn from a normal population.

One of the common uses of "Student's" t -test is to compare the mean of a population with some standard. In practical problems, however, it is often the case that the distribution

of the population being sampled is not known or is not normal. It is therefore desirable that some measure of the degree of error be obtained for "Student's" t-test when the assumption of normality of the sample is violated.

Literature reveals that a great deal of research has been directed towards many aspects of "Student's" distribution. In 1925, R. A. Fisher very stringently verified the independence of the sample mean \bar{x} and the sample variance s^2 . This was one of the basic assumptions in the development of "Student's" distribution [2]. In 1936, R. C. Geary investigated the distribution of "Student's" t ratio for the samples drawn from a slightly asymmetrical universe by developing asymptotic formulae for the moments of the t distribution. He showed that for symmetrical, non-normal populations, "Student's" distribution gives more accurate results than skewed sampling distributions.

(4) In 1948, A. K. Gayen, using the moments techniques, studied the behavior of "Student's" t and obtained results similar to those obtained by R. C. Geary in 1936 [5]. In more recent work, Cucconi [6] developed a simple relation between the critical values of "Student's" t and the degrees of freedom. Through this relation, in addition to deriving the critical values of t for any number of degrees of freedom, he showed that it is possible to substitute "Student's" criteria in the verification of statistical hypothesis more easily than using a standardized normal deviation [9]. These are but a few examples of the diversified attention given to "Student's"

t-test. The aim of this paper is to investigate the robustness of "Student's" t-test when the sampling data is drawn from the Beta and the Gamma distributions.

III. METHODS AND PROCEDURES

In order to investigate the robustness of t-test, it was decided to select two well known distributions with a wide scope of application in the real world. The two distributions selected are the Gamma and Beta distributions. A brief description of these distributions follows.

A. GAMMA DISTRIBUTION

A continuous random variable Y is said to have the Gamma distribution if its density is

$$f(y) = \frac{1}{\Gamma(\alpha) \beta^\alpha} y^{\alpha-1} e^{-\frac{y}{\beta}}, \quad 0 < y < \infty$$
$$= 0, \quad \text{otherwise}$$

It should be noted that this is a two parameter family of distributions with parameters α and β . The distribution is only defined when the value of $\alpha > -1$, and the value of $\beta > 0$. The mean and variance of this distribution are respectively $\alpha\beta$ and $\alpha\beta^2$. The Gamma distribution is frequently applied to the solution of the queuing and inventory control problems. A graphical representation of the Gamma distribution for various values of its parameters is given in Appendix A.

One of the special and most often used family of Gamma distributions is called the Erlang distribution. In order to obtain this distribution, the values of the parameter α in the Gamma distribution are restricted to positive integer values and this positive integer is denoted by K. If one replaces

β by $\frac{1}{\lambda}$, then the distribution becomes

$$f(y) = \frac{\lambda (\lambda y)^{K-1} e^{-\lambda y}}{(K-1)!} \quad \text{for } y \geq 0$$

$$= 0, \text{ otherwise}$$

It is possible to show that the latter $f(y)$ can be generated by the sum of K variates Z having the exponential density

$$f(z) = \lambda e^{-\lambda z} \quad \text{when } z > 0$$

$$= 0, \text{ otherwise}$$

It should be noted that when $K = 1$, we have the exponential density as a special case. The mean, variance and mode of the Erlang distribution are $\frac{K}{\lambda}$, $\frac{K}{\lambda^2}$ and $\frac{K-1}{\lambda}$ respectively. The great usefulness of this distribution stems from the fact that it is a large family of distributions permitting only non-negative values. The waiting time and the service time distributions in the queuing theory can, therefore, be reasonably approximated by an Erlang distribution.

B. THE BETA DISTRIBUTION

A continuous random variable Z is said to have a Beta distribution when

$$f(z) = \frac{\Gamma(\alpha+\beta)}{\Gamma(\alpha)\Gamma(\beta)} z^{\alpha-1} (1-z)^{\beta-1} \quad \text{when } 0 \leq z \leq 1$$

$$= 0, \text{ otherwise}$$

This density is a function of the two parameters α and β , both of which are positive constants. The mean and variance of

this distribution are given by $\frac{\alpha}{\alpha+\beta}$ and $\frac{(\alpha+1)(\beta+1)}{(\alpha+\beta+2)^2(\alpha+\beta+3)}$. A

graphical representation of the Beta distribution for various values of the parameters is furnished in Appendix B.

It may be pointed out that when $\alpha=\beta=0$ the distribution becomes the uniform distribution over the unit interval. The Beta distribution, though in general defined over the unit interval, can also be defined over any interval (a, b) as follows

$$f(z) = \xi (z-a)^\alpha (b-z)^\beta \quad \text{where } a \leq z \leq b$$

$$= 0, \text{ otherwise}$$

$$\text{where } \xi = \frac{1}{\int_a^b (z-a)^\alpha (b-z)^\beta dz}$$

Primarily because the Beta distribution is defined on a finite interval, it is widely used in the study of critical path scheduling techniques such as PERT. It may be recalled that PERT is a method of reflecting the uncertainties associated with development-type tasks, and its use generally results in providing a more realistic outlook for task accomplishment than the conventional systems provided in the past. In order to obtain the critical path through the network, it is necessary that a distribution defined between the pessimistic and optimistic time estimates adequately represent the distribution of time required to perform an activity. Since the Beta distribution restricts the probability distribution to a finite range for varying values of the parameters, it is widely used in the critical path scheduling.

C. GENERATION OF DISTRIBUTIONS

The inverse probability integral transformation technique is used to produce random variates having the exponential distribution. According to this technique, the cumulative distribution function for the uniform probability density function on the interval (0,1) is equated to the cumulative distribution function for the desired probability density function in order to obtain the necessary transformation. Thus if RN denotes a random variable on the interval (0,1), and λ is the desired parameter of the exponential distribution; then the random variable obtained from the transformation $X = \frac{-\ln(RN)}{\lambda}$ is exponentially distributed with a mean $\mu = \frac{1}{\lambda}$.

1. Erlang Distribution

In order to generate the Erlang distribution, an extension of the above procedure is utilized by first generating exponential random variables with mean $\frac{1}{\lambda}$. Then K of these exponential variates are summed using the relationship

$X = \sum_{i=1}^N \frac{\ln(RN)_i}{-\lambda}$ to produce the desired Erlang distribution with mean $= \frac{K}{\lambda}$ and variance $\frac{K}{\lambda^2}$.

2. Beta Distribution

The Beta distribution is generated using the following theoretical ideas. Consider two random samples X_1, X_2, \dots, X_n and Y_1, Y_2, \dots, Y_m such that the random variables X and Y are identically distributed exponential with parameter λ . If we

form the statistics $z_1 = \sum_{i=1}^n X_i$ and $z_2 = \sum_{i=1}^m Y_i$ then

$$z_1 \sim \Gamma(z_1; n, \mu)$$

$$z_2 \sim \Gamma(z_2; m, \mu)$$

and their joint density function is given by

$$g(z_1, z_2) = \frac{z_1^{n-1} z_2^{m-1} e^{-\frac{z_1+z_2}{\mu}}}{\Gamma(n) \Gamma(m) \mu^{m+n}}, \quad 0 < z_1 < \infty \text{ and } 0 < z_2 < \infty$$

Now using the transformation $w_1 = \frac{z_1}{z_1+z_2}$ and $w_2 = z_1+z_2$, the joint density of w_1 and w_2 is given by:

$$h(w_1, w_2) = \frac{(w_1 w_2)^{n-1} w_2^{m-1} (1-w_1)^{m-1} e^{-\frac{w_2}{\mu}}}{\Gamma(n) \Gamma(m) \mu^{m+n}} \cdot w_2$$

Integrating over the domain of w_2 , the marginal density of w_1 ;

$$h(w_1) = \int_0^\infty h(w_1, w_2) dw_2$$

$$\text{i.e., } h(w_1) = \frac{w_1^{n-1} (1-w_1)^{m-1}}{\Gamma(n) \Gamma(m) \mu^{n+m}} \int_0^\infty w_2^{n+m-1} e^{-\frac{w_2}{\mu}} dw_2$$

Using the substitution $U = w_2/\mu$ and $dw_2 = \mu du$ we get:

$$\begin{aligned} h(w_1) &= \frac{w_1^{n-1} (1-w_1)^{m-1}}{\Gamma(n) \Gamma(m)} \int_0^\infty u^{n+m-1} e^{-u} du \\ &= \frac{\Gamma(n+m)}{\Gamma(n) \Gamma(m)} w_1^{n-1} (1-w_1)^{m-1} \end{aligned}$$

We observe that $W_1 = \frac{Y_1}{Y_1+Y_2}$ has the Beta distribution

with $\alpha=n$, $\beta=m$, and this Beta distribution is independent of the parameter of the exponential distribution provided that the two Gamma distributions are generated by random numbers having identical exponential distributions. Thus to generate the Beta distribution, two Gamma distributions with parameters $(K_1, \frac{1}{\lambda})$ and $(K_2, \frac{1}{\lambda})$ are generated using the above techniques. From these distributions, the ratio $W_1 = \frac{Y_1}{Y_1+Y_2}$ is formed to obtain a Beta distributed random variable with mean = $\frac{K_1}{K_1+K_2}$ and variance $\frac{K_1 K_2}{(K_1+K_2)^2 (K_1+K_2+1)}$.

D. SIMULATION TECHNIQUES

The accuracy of generating random observations from a probability distribution depends upon the characteristics of the uniform random number generator. At least the superficial characteristics of the random number generator are ascertained by the use of chi-square test for goodness-of-fit at 95% and 99% significance levels. For the chi-square test, the unit interval is divided into fifty equal intervals. Each generated random number is assigned to one of the fifty categories according to its size. From this data, a measure of the discrepancy existing between observed and expected frequencies is obtained using the relationship $\chi^2 = \sum_{i=1}^T \frac{(o_i - e_i)^2}{e_i}$ where o_i denotes the observed frequency of the i th category, and e_i

denotes the expected or theoretical frequencies of this occurrence; T denotes the total number of categories. The number of degrees of freedom for the statistics is equal to $T-1$, where T is the number of categories or classes.

For the purpose of this project, four simulated distributions were obtained for each type of distribution sampled. Each simulation utilizes 5000 samples and a fixed sample size. In the discussion throughout this paper, sample size is referred to as the number of data points within each sample used to calculate the t statistic and the number of samples denotes the number of replications for fixed values of the parameters within each cycle. In order to obtain different shapes of the distribution, five different sets of values of the parameters are then used within each simulation.

Since the basic techniques and procedures employed in each of the four simulations for the Erlang and the Beta distributions are essentially the same, it is considered adequate to discuss the methodology of one simulation for each distribution in detail.

1. Erlang Distribution

Simulation 1 for the Erlang distribution consists of four steps. Step I consists of five cycles. For each cycle, 5000 samples of size 5 are independently generated from the Erlang distribution using the values of the parameters as shown in Table 1 below. For the purpose of discussion, these sampling distributions are referred to as $\gamma(K, \lambda)$

TABLE 1

| Cycle # | Cycle 1 | Cycle 2 | Cycle 3 | Cycle 4 | Cycle 5 |
|--|------------------------|------------------------|------------------------|------------------------|------------------------|
| Value of Parameters $\gamma(K, \lambda)$ | K = 4 $\lambda = 3$ | K = 5 $\lambda = 3$ | K = 6 $\lambda = 3$ | K = 7 $\lambda = 3$ | K = 8 $\lambda = 3$ |
| Mean | 1.333 | 1.667 | 2.0 | 2.333 | 2.667 |
| Standard Deviation | .6669 | .7408 | .8200 | .8624 | .9368 |

To illustrate the use of Table 1, 5000 samples of size 5 are generated during cycle 1 using parameters $K = 4$, $\lambda = 3$. The mean and standard deviation of this Erlang distribution are given in rows 3 and 4 of Table 1. During Cycle 2, another 5000 samples of size 5 are independently generated from the Erlang distribution using parameters $K = 5$, $\lambda = 3$. The mean and standard deviation of this distribution are 1.667 and .7408 respectively. These values are furnished in rows 3 and 4 of Table 1 under the heading Cycle 2. The same process is repeated for Cycles 3, 4, and 5 using the appropriate parameters.

In Step II, for each sample the statistic $t = \frac{\bar{x} - \mu}{s/\sqrt{N}}$

is calculated where \bar{x} is sample mean, s is sample standard deviation, $N =$ sample size (5), and μ is population mean (1.33). The absolute values of this statistic are then compared with the corresponding values from the "Student's" t-distribution

with $N-1$ degrees of freedom and at significance levels $\alpha=.8, .5, .2, .1, .05, .02, .01$, and $.001$. These values of "Student's" t -distribution with varying degrees of freedom and significance levels are generally referred to as the critical values t_α of t -distribution and are the solutions to the equation $1-\frac{\alpha}{2} = \int_{-\infty}^{t_\alpha} f(t)dt$ for various values of α . The number of t statistics whose absolute values are greater than the corresponding critical values at each significance level are recorded for comparison purposes.

In order to fully understand the comparisons between the actual significance levels and the significance levels obtained from the Erlang distribution, it is necessary that some knowledge regarding the comparisons between the distribution frequencies be known. This is accomplished in Step III by transforming the total number of data points for the Erlang distribution in each cycle ($5000 \times 5 = 25,000$) using the transformation $\frac{X_i - \mu}{\sigma}$, $i = 1, 25000$, where μ and σ are the sampling distribution mean and standard deviation respectively. The transformed distribution is called $\gamma(0,1)$. It may be pointed out that if the sampling distribution were normal, with mean μ and standard deviation σ then this transformation $\frac{X-\mu}{\sigma}$ would reduce the sampling distribution to what is called Standard Normal, mean zero, variance unity. This is generally denoted by $N(0,1)$. The transformed distribution, $\gamma(0,1)$ is then divided into four intervals of width unity on either side of assumed mean of zero, and the frequency counts within each

interval are recorded. These counts are then compared with the expected number of frequency counts within each interval assuming that the sampling distribution was normal.

In Step IV, the chi-square goodness-of-fit test, using a significance level of 0.05, is conducted on the results of the observed significance levels and the distribution frequencies as calculated in Steps II and III above. This concludes Cycle 1 of Simulation 1. For Cycles 2, 3, 4, and 5, the entire procedure as outlined above is repeated by changing the parameters of the $\gamma(K_1, \lambda)$ distribution in accordance with Table 1.

Simulations 2, 3, and 4 for the Erlang distribution use exactly the same techniques as outlined under Simulation 1 except that the sample sizes are 10, 15, and 20 respectively.

2. Beta Distribution

Simulation 1 for the Beta distribution is conducted in four steps. Step I consists of five cycles which are shown in Table 2. For each cycle, 5000 samples of size 5 are independently generated from each of the two Erlang distributions using fixed values of the parameters as shown in Table 2. These distributions are referred to as $\gamma_1(K_1, \lambda)$ and $\gamma_2(K_2, \lambda)$.

TABLE 2

| Cycle Number | Cycle 1 | Cycle 2 | Cycle 3 | Cycle 4 | Cycle 5 |
|---|----------------------------|----------------------------|----------------------------|----------------------------|----------------------------|
| Values of Parameters $\gamma_1(K_1, \lambda)$ | $K_1 = 4$ $\lambda = 3$ | $K_1 = 4$ $\lambda = 3$ | $K_1 = 4$ $\lambda = 3$ | $K_1 = 4$ $\lambda = 3$ | $K_1 = 4$ $\lambda = 3$ |
| Values of Parameters $\gamma_2(K_2, \lambda)$ | $K_2 = 4$ $\lambda = 3$ | $K_2 = 5$ $\lambda = 3$ | $K_2 = 6$ $\lambda = 3$ | $K_2 = 7$ $\lambda = 3$ | $K_2 = 8$ $\lambda = 3$ |
| Mean (Beta) | .5 | .44 | .40 | .36 | .33 |
| STD. DEV. (Beta) | .167 | .1589 | .150 | .140 | .1329 |

To illustrate the use of Table 2, 5000 samples of size 5 are generated for $\gamma_1(K_1, \lambda)$ distribution using the parameters $K_1 = 4$ and $\lambda = 3$. Another 5000 samples of size 5 are independently generated for $\gamma_2(K_2, \lambda)$ distribution using parameters $K_2 = 4$ and $\lambda = 3$ as shown in Table 2. During Cycle 2, 5000 samples of size 5 for each of the $\gamma_1(K_1, \lambda)$ and $\gamma_2(K_2, \lambda)$ distributions are independently generated using the parameters $K_1 = 4$, $\lambda = 3$ and $K_2 = 5$, $\lambda = 3$ respectively. These values are found in Table 2 under the heading Cycle 2. A similar process is repeated for the remaining Cycles 3, 4, and 5.

For each cycle, the $\gamma_1(K_1, \lambda)$ and $\gamma_2(K_2, \lambda)$ distributions are combined using the relationship $\gamma_1(K_1, \lambda) / \{\gamma_1(K_1, \lambda) + \gamma_2(K_2, \lambda)\}$ to form five 5000 samples of size 5 for the Beta distribution having mean = $\frac{K_1}{K_1 + K_2}$ and variance $\frac{K_1 K_2}{(K_1 + K_2)^2 (K_1 + K_2 + 1)}$.

The actual values of these calculations for each cycle are shown in Table 2. It should be apparent that each cycle generates 5000 samples of size 5 from a different Beta distribution.

The remaining Steps II, III, and IV of this simulation are identical with Steps II, III, and IV of Simulation 1 under the Erlang distribution. Simulations 2, 3, and 4 for the Beta distribution use exactly the same techniques as outlined in Simulation 1 except that the sample sizes are 10, 15, and 20 respectively.

In addition, the effects of changes in the variance of the Beta distribution, when the mean is kept constant, are also investigated. This is accomplished by manipulating the values of the $\gamma_1(K_1, \lambda)$ and $\gamma_2(K_2, \lambda)$ parameters that result in Beta distributions having the same mean but different variances. The sets of values of these parameters used during this simulation are furnished in Table 3 below.

TABLE 3

| Cycle # | Cycle 1 | Cycle 2 | Cycle 3 | Cycle 4 | Cycle 5 |
|---|----------------------------|----------------------------|----------------------------|----------------------------|-----------------------------|
| Parameters of $\gamma_1(K_1, \lambda)$ | $K_1 = 2$ $\lambda = 3$ | $K_1 = 4$ $\lambda = 3$ | $K_1 = 6$ $\lambda = 3$ | $K_1 = 8$ $\lambda = 3$ | $K_1 = 10$ $\lambda = 3$ |
| Parameters of $\gamma_2(K_2, \lambda)$ | $K_2 = 2$ $\lambda = 3$ | $K_2 = 4$ $\lambda = 3$ | $K_2 = 6$ $\lambda = 3$ | $K_2 = 8$ $\lambda = 3$ | $K_2 = 10$ $\lambda = 3$ |
| Mean (Beta) | .5 | .5 | .5 | .5 | .5 |
| STD. DEV. (Beta) | .036 | .022 | .0195 | .013 | .011 |

IV. RESULTS

The results of the various simulations for the Erlang and Beta distributions are furnished in tabular form in appendices C, D, E, F, G, and H. Appendix C contains Tables 4, 5, 6, and 7. These tables contain the frequency comparisons of the distributions obtained in these simulations and from Standard Normal designated $N(0,1)$, when samples of size, 5, 10, 15, and 20 are used respectively. Tables 8, 9, 10, and 11 in Appendix D contain similar results obtained from the use of Beta distributions. Appendix E contains Tables 12 and 13. These tables have the comparison of the frequency distributions from $N(0,1)$ and the transformed $Beta(0,1)$ when the mean of the distribution is kept constant, and its variance is manipulated.

Appendices F, G, and H contain five tables each. These tables provide the necessary comparisons between the actual and observed significance levels for a fixed mean and 4, 9, 14, and 19 degrees of freedom. Tables 14, 15, 16, 17, and 18 in Appendix F pertain to Erlang distribution and contain the comparisons of the actual and the observed significance levels when samples of size 5, 10, 15, and 20 are used respectively. Tables 19, 20, 21, 22, and 23 in Appendix G contain similar results for the Beta distributions. Tables 24, 25, 26 27, and 28 in Appendix H have the comparisons of the significance levels when the variance of the Beta distribution is manipulated for a fixed mean.

Since there are but two different table formats used to illustrate the results, it is considered appropriate to discuss the use of only one table of each type before proceeding with

the discussion of the results. Tables of the first type, which give frequency comparisons, are used in Appendices C, D, and E. The second type of table is used to provide the comparisons of significance levels, and these tables are contained in Appendices F, G, and H.

As mentioned earlier, Table 4 pertains to the Erlang distribution. This table is divided into two parts. Part I furnishes the means and the standard deviations of the sampling distributions when the samples of size 5 are used. The means and standard deviations for each distribution are identified by means of index numbers. For example, Index (1) pertains to the Erlang distribution with mean 1.33 and standard deviation .6669. Part II of this table furnishes the frequency distributions of each Erlang given in Part I and the frequency distributions of $N(0,1)$. In order to relate the mean and variance with the corresponding frequency distributions, the appropriate index should be consulted. For example, if one wishes to compare the frequency distribution of an Erlang with mean 2.0 and standard deviation .82, when using samples of size 5; one should consult Appendix C, Table 4. Corresponding to the above values, one would select Index 3 from Part I of Table 4 and obtain the frequency distribution from the row (3) in Part II of this table. In order to compare this frequency distribution with $N(0,1)$, one would compare the corresponding values of row 3 with the row marked $N(0,1)$. The asterisks on the distribution frequencies indicate that the distribution

was found to be significantly different than $N(0,1)$ by chi-square goodness-of-fit test at 95% confidence level.

The second type of table is found in Appendices F, G, and H. Table 15 in Appendix F pertains to the Erlang distribution with a fixed mean of 1.667. This table provides the comparison of the actual significance levels and the observed significance levels when the sampling population is Erlang with mean 1.667. This table furnishes these comparisons for four values of degrees of freedom. These values are 4, 9, 14, and 19; they are found in the first column of the table. The format of this table is very similar to the standard t-table found in most text books. In order to make use of this table, one is required to know the sample size and the population mean. For example, if one is interested in determining the comparison of significance levels; when sampling from Erlang distribution with mean 2.0 using sample size 15, one would consult Appendix F, Table 16 and obtain the required information in the row marked 14. The asterisks on the observed significance values indicate that the results were found to be significantly different at 95% confidence level by the use of chi-square goodness-of-fit test.

RESULTS OF ERLANG

The results shown in Tables 4, 5, 6, and 7 indicate that the Erlang frequency distributions are significantly different than the $N(0,1)$ at 5% level. A comparison of the observed significance levels with the actual significance levels in

Table 14, Appendix F reveals that when an Erlang distribution with mean 1.333 is used the observed alpha values are significantly different from the actual alpha values. For example, for Sample Size 5, corresponding to the actual values of $\alpha = .5, .2, \text{ and } .05$; the observed values are $\alpha = .034, .004, \text{ and } .0004$ respectively. It is further noted that as the sample size is increased to 10, 15, and 20, the corresponding observed values are zero in each case. This means that all the absolute values of t statistic are smaller than the critical values.

From the results in Table 15, one observes that for sample size 5 at $\alpha = .5, .2, .05$, the observed values are $\alpha = .0292, .002, \text{ and } .0002$ respectively. Each of these values is smaller than the corresponding values in Table 14. The results for sample size 10, 15, and 20 are the same as found in Table 14. The results in Tables 16 and 17 indicate that for sample size 5, the corresponding observed values in each case are $\alpha = .0292, .0034, .0002$ and $.0268, .0028, .0002$ respectively. The alpha values for sample sizes 10, 15, and 20 remain zero.

In examining the graphs of these distributions, one observes that as the mean of the distribution is increased; the distribution, though flatter than the normal distribution, becomes more nearly symmetric around the mean. However as the mean of the distribution is increased, the variance ($\frac{K}{\lambda^2}$) is also increased. Consequently, when sampling from this distribution, the absolute values of the t statistic, $\frac{\bar{x}-\mu}{s/\sqrt{N}}$, are

smaller than the absolute values of this statistic when sampling from the normal population. Furthermore, these values decrease as the sample size is increased.

From the foregoing results, it is concluded that "Student's" t-test is sensitive to the Erlang distribution. It is further observed that when sampling from an Erlang distribution, the resulting t statistic has significantly shorter tails than the "Student's" t distribution. It would seem, therefore, that the resulting t statistic is a form of leptokurtic curve.

RESULTS OF BETA DISTRIBUTION

Results in Tables 8, 9, 10, and 11 reveal that except when the sample size is 20; and the distribution is symmetric around the mean (.5), the Beta distribution frequencies are significantly different from the $N(0,1)$. A comparison of the results in Table 19, Appendix G reveals that when sampling from the Beta distribution with mean .5, the observed alpha values in most cases are not significantly different from the actual alpha values. For example, for sample size 5, the observed alpha values are only significant at $\alpha = .8$ and .5. However, when the sample size is increased to 10, 15, and 20; the results are only significant at $\alpha = .8$. This suggests that when sampling from a symmetric Beta distribution, using samples of size 5 or greater, the "Student's" t-test yields results that are comparable with results obtained from normal sampling distributions.

The results in Table 20 reveal that when sampling from the Beta distribution with mean .44, the observed alpha values

for sample size 10 remain unchanged. The observed alpha values using sample size 5 are significantly different at $\alpha = .8$, $.5$, and $.2$. The observed alpha values for sample size 20 are significant at $\alpha = .8$, $.5$, $.1$ and $.05$. Comparing similar results in Tables 21 and 22, one observes that as the mean of the sampling distribution is varied to the left of the mean, the use of larger sample sizes (10, 15) yield observed alpha values that are comparable to the actual alpha values. In Table 23, one observes that when the sampling distribution has mean $.33$; i.e., it is significantly skewed to the right, the observed alpha values for sample size 5 are significantly different than the actual alpha values. The results for sample size 10 are reasonably comparable with the actual alpha values.

From the foregoing, it is concluded that the "Student's" t-test is sensitive to changes in the shape resulting from changes in the mean of the distribution. When the Beta distribution is symmetric around the mean, the use of "Student's" t-test yields results that are comparable with those obtained when sampling from the normal population. It is further noted that most of the observed alpha values are smaller than the actual alpha values. This suggests that the values of the t statistic are smaller than the corresponding values of "Student's" t statistic. It would seem that the tails of the new t statistic are shorter than the tails of "Student's" t.

The results of the Beta distributions with fixed mean and different variances are contained in Tables 24, 25, 26,



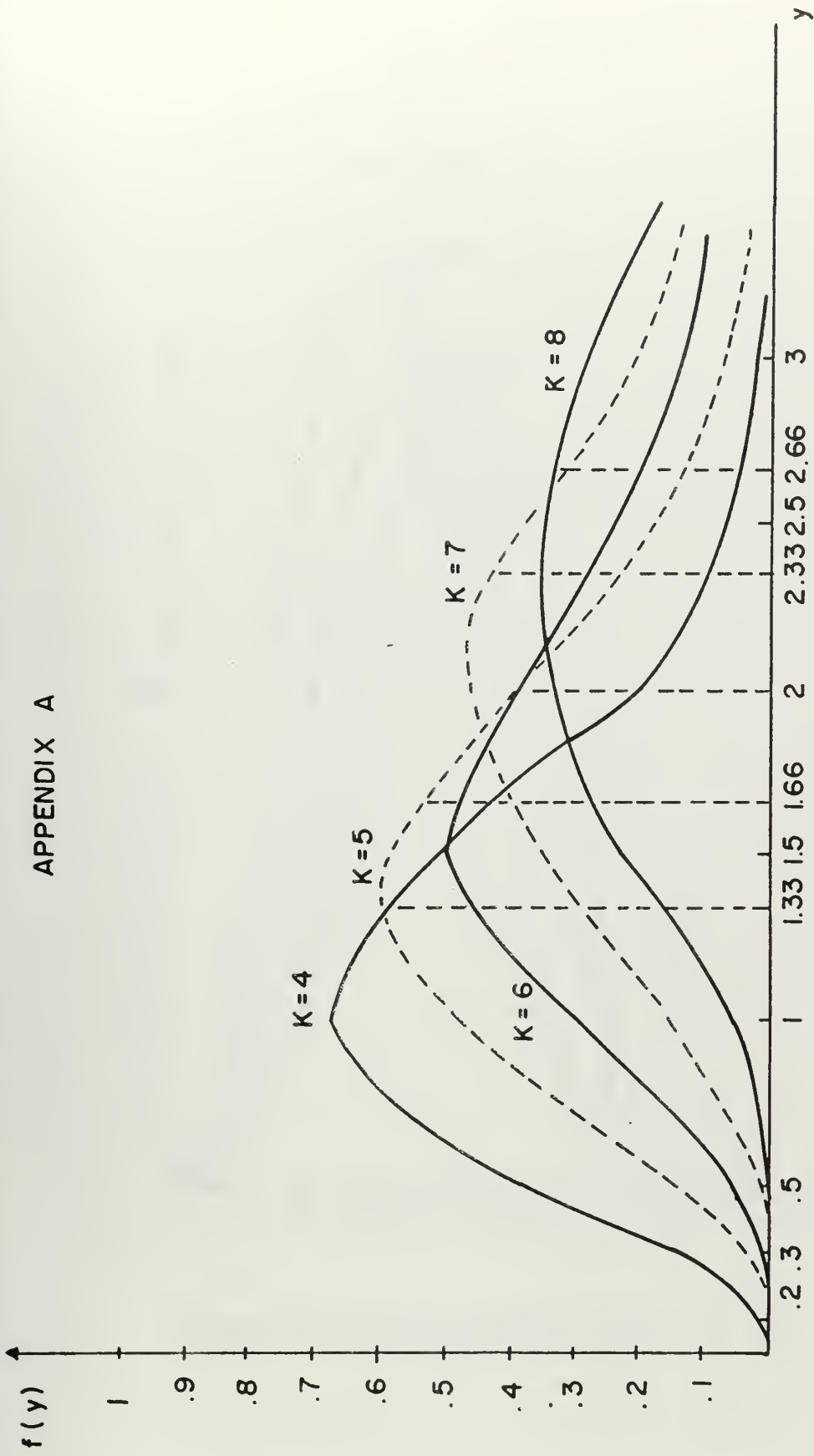
27, and 28. A similar investigation of these results indicates that for small sample size (5) the observed alpha values are significantly different than the true values. However, as the sample size is increased to 10, the difference between the observed and actual alpha values is significantly reduced. This suggests that "Student's" t-test is sensitive to changes in the variance when small samples are used.

V. CONCLUSIONS AND RECOMMENDATIONS

The simulation described on the foregoing pages which investigated the robustness of "Student's" t-test has proven to be extremely realistic. The results of violating the assumption of normality by the use of the Beta and the Gamma distributions indicate that when the sampling distribution is symmetric around the mean, the use of "Student's" t-test gives results that are closely comparable with the values obtained by the use of normal distributions. This implies that "Student's" t-test is reasonably robust when it is used with symmetric populations. The results also indicate that in the case of skewed distributions, the observed alpha values are significantly different from the actual significance levels. It is further noted that in the case of symmetric distributions, the values of observed significance levels approach the true values as the sample size is increased.

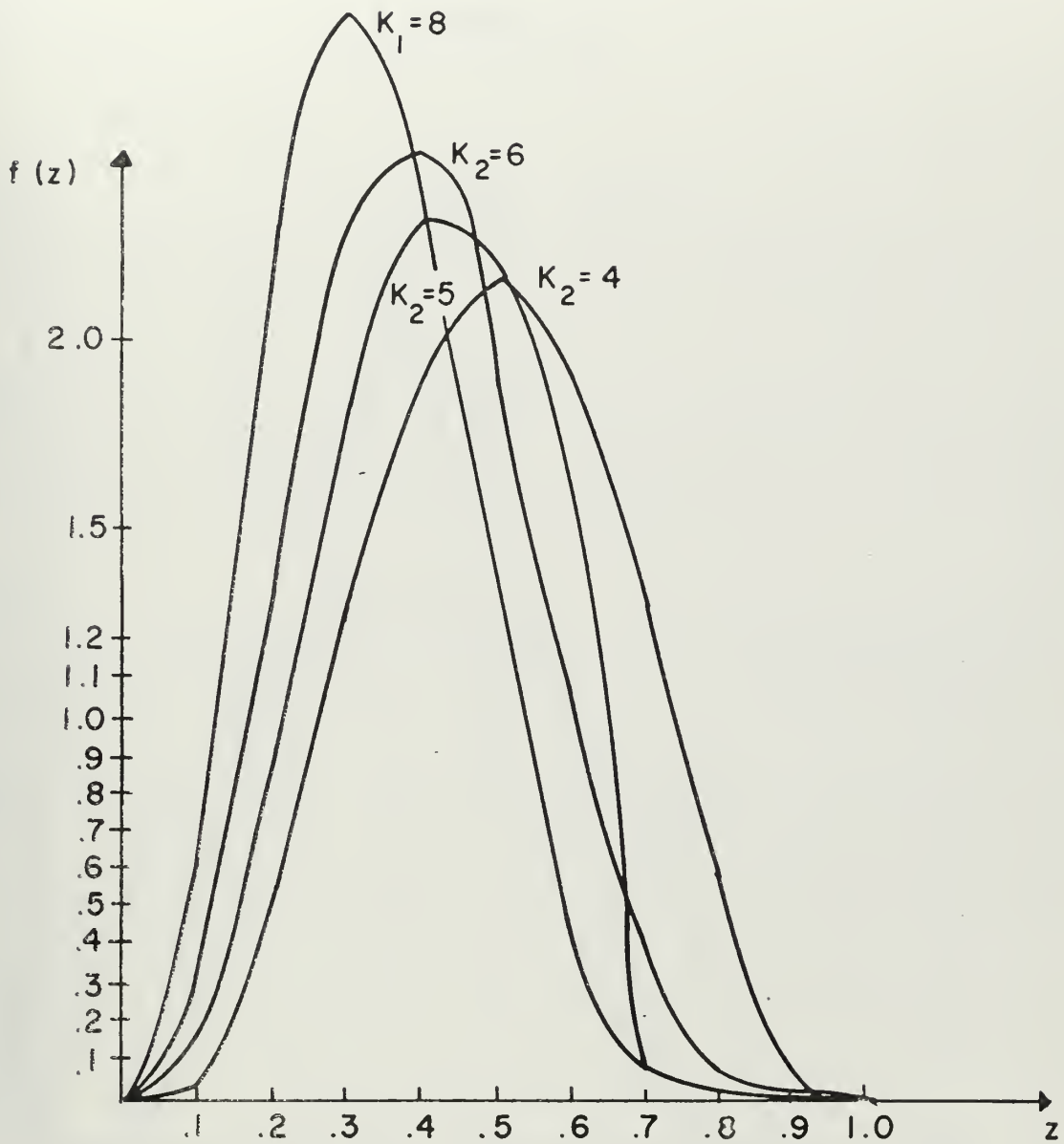
In the case of symmetrical distributions with a fixed mean and different variances, it is observed that the "Student's" t-test is sensitive to the change in the variance. The observed significance levels are considerably different from the true values as the variance of the sampling population is increased. However, as the sample size is increased, the effects of change in the variance are considerably reduced.

APPENDIX A



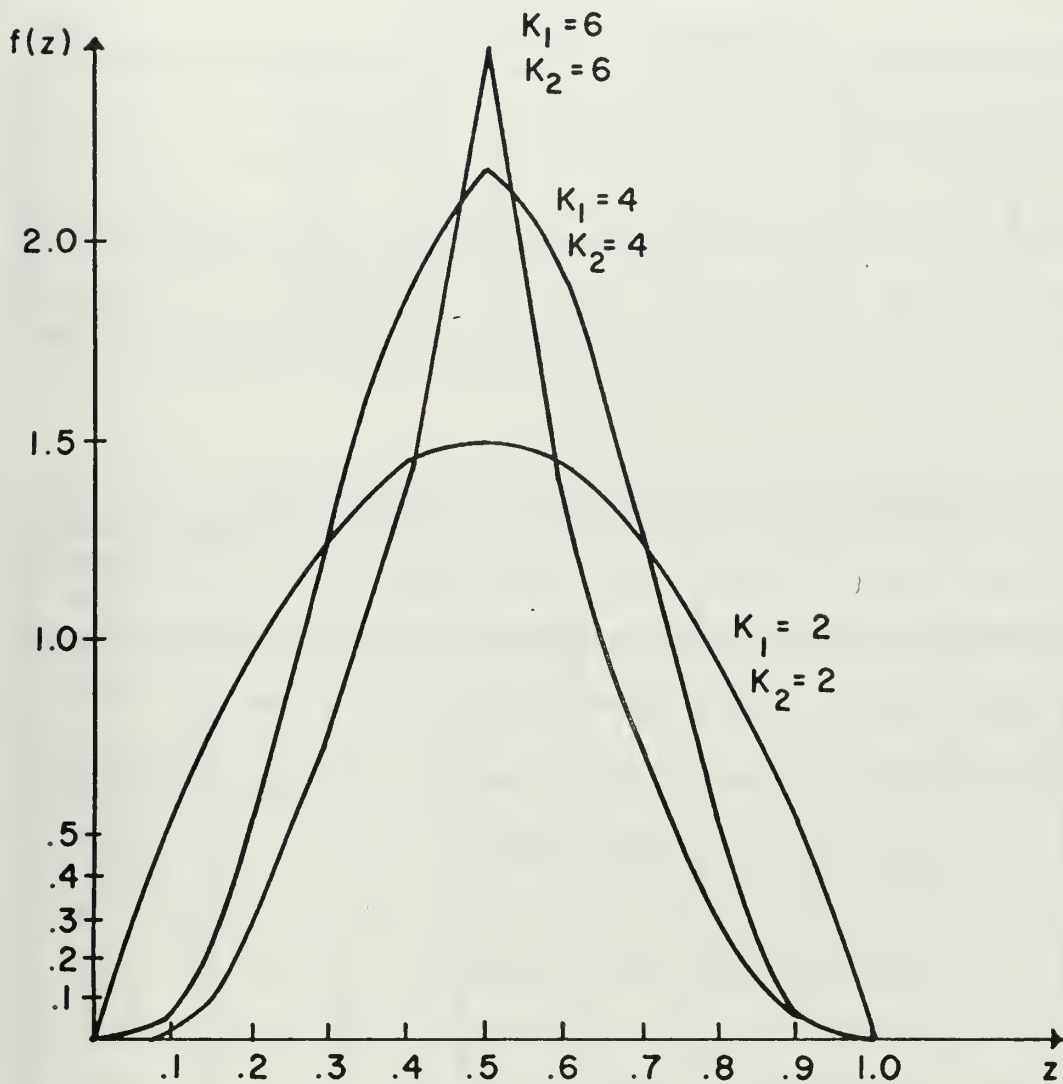
GRAPHS OF ERLANG DISTRIBUTIONS FOR $\lambda = 3$

APPENDIX B



GRAPH OF BETA DISTRIBUTIONS $\alpha = K_1 = 4$

APPENDIX B₁



GRAPH OF BETA DISTRIBUTIONS WITH MEAN = 0.5 ,
DIFFERENT VARIANCE.

APPENDIX C

Table 4

POPULATION Erlang

SAMPLE SIZE 5

Part I Population Parameters

| | | | | | |
|----------|-------|-------|-----|-------|-------|
| Mean | 1.33 | 1.667 | 2.0 | 2.333 | 2.667 |
| STD.DEV. | .6669 | .74 | .82 | .86 | .93 |
| Index | (1) | (2) | (3) | (4) | (5) |

Part II Comparisons of Distribution Frequencies

| Inter- vals | < $\mu-3\sigma$ | $\mu-\sigma$ | $\mu-\sigma$ | $\mu-\sigma$ | $\mu+\sigma$ | $\mu+\sigma$ | $\mu+\sigma$ | > $\mu+3\sigma$ |
|----------------|--------------------|--------------|--------------|--------------|--------------|--------------|--------------|--------------------|
| N(0,1) | 74 | 524 | 3399 | 8499 | 8499 | 3399 | 524 | 74 |
| $\gamma(0,1)$ | | | | | | | | |
| Index (1)* | 0 | 0 | 3581 | 10575 | 6991 | 2793 | 813 | 247 |
| (2)* | 0 | 10 | 3653 | 10250 | 7244 | 2820 | 990 | 233 |
| (3)* | 0 | 26 | 3699 | 10161 | 7262 | 2841 | 774 | 237 |
| (4)* | 0 | 62 | 3797 | 9743 | 7469 | 2948 | 802 | 179 |
| (5)* | 0 | 75 | 3824 | 9762 | 7390 | 2490 | 782 | 177 |

APPENDIX C

Table 5

POPULATION: Erlang

SAMPLE SIZE: 10

Part I Population Parameters

| | | | | | |
|----------|-------|-------|-----|------|-------|
| Mean | 1.333 | 1.667 | 2.0 | 2.33 | 2.667 |
| STD.DEV. | .6604 | .749 | .83 | .905 | .9755 |
| Index | (1) | (2) | (3) | (4) | (5) |

Part II Comparison of Distribution Frequencies

| Inter- vals | < $\mu-3\sigma$ | $\mu-3\sigma$ | $\mu-2\sigma$ | $\mu-\sigma$ | $\mu+\sigma$ | $\mu+2\sigma$ | $\mu+3\sigma$ | > $\mu+3\sigma$ |
|----------------|--------------------|---------------|---------------|--------------|--------------|---------------|---------------|--------------------|
| N(0,1) | 149 | 1049 | 6799 | 16999 | 16999 | 6799 | 1049 | 149 |
| $\gamma(0,1)$ | | | | | | | | |
| Index (1)* | 0 | 1 | 7294 | 20977 | 14043 | 5495 | 1670 | 520 |
| (2)* | 0 | 11 | 7029 | 20628 | 14691 | 5610 | 1572 | 459 |
| (3)* | 0 | 39 | 6854 | 20464 | 15090 | 5636 | 1500 | 417 |
| (4)* | 0 | 46 | 6702 | 20443 | 15197 | 5819 | 1447 | 346 |
| (5)* | 0 | 78 | 6670 | 20394 | 15226 | 5822 | 1490 | 320 |

APPENDIX C

Table 6

POPULATION: Erlang

SAMPLE SIZE: 15

Part I

Population Parameters

| | | | | | |
|----------|-------|-------|-------|-------|-------|
| Mean | 1.33 | 1.667 | 2.0 | 2.333 | 2.667 |
| STD.DEV. | .6725 | .7677 | .8466 | .9173 | .9983 |
| Index | (1) | (2) | (3) | (4) | (5) |

Part II

Comparisons of Distribution Frequencies

| Inter- vals | < $\mu-3\sigma$ | $\mu-3\sigma$ | $\mu-2\sigma$ | $\mu-\sigma$ | $\mu+\sigma$ | $\mu+2\sigma$ | $\mu+3\sigma$ | > $\mu+3\sigma$ |
|----------------|--------------------|---------------|---------------|--------------|--------------|---------------|---------------|--------------------|
| N(0,1) | 224 | 1574 | 10199 | 25499 | 25499 | 10199 | 1574 | 224 |
| $\gamma(0,1)$ | | | | | | | | |
| Index (1)* | 0 | 0 | 10018 | 31845 | 21764 | 8223 | 2423 | 724 |
| (2)* | 0 | 4 | 9739 | 31562 | 22509 | 8283 | 2216 | 687 |
| (3)* | 0 | 25 | 9802 | 31101 | 22752 | 8495 | 2272 | 553 |
| (4)* | 0 | 54 | 9750 | 30661 | 23129 | 8783 | 2139 | 484 |
| (5)* | 0 | 75 | 9763 | 30455 | 23504 | 8666 | 2082 | 455 |

APPENDIX C

Table 7

POPULATION: Erlang

SAMPLE SIZE: 20

Part I Population Parameters

| | | | | | |
|----------|-------|-------|-------|-------|-------|
| Mean | 1.33 | 1.667 | 2.0 | 2.333 | 2.667 |
| STD.DEV. | .6825 | .7710 | .8536 | .9232 | .9957 |
| Index | (1) | (2) | (3) | (4) | (5) |

Part II Comparisons of Distribution Frequencies

| Inter- vals | < $\mu-3\sigma$ | $\mu-3\sigma$ | $\mu-2\sigma$ | $\mu-\sigma$ | $\mu+\sigma$ | $\mu+2\sigma$ | $\mu+3\sigma$ | > $\mu+3\sigma$ |
|----------------|--------------------|---------------|---------------|--------------|--------------|---------------|---------------|--------------------|
| N(0,1) | 299 | 2099 | 13599 | 33999 | 33999 | 13599 | 2099 | 299 |
| $\gamma(0,1)$ | | | | | | | | |
| Index (1)* | 0 | 0 | 12775 | 43055 | 29172 | 11113 | 3142 | 943 |
| (2) | 0 | 5 | 12569 | 42147 | 30198 | 11222 | 3055 | 809 |
| (3)* | 0 | 30 | 12625 | 41768 | 30649 | 11277 | 2897 | 754 |
| (4)* | 0 | 69 | 12582 | 41276 | 31091 | 11553 | 2798 | 631 |
| (5)* | 0 | 109 | 12587 | 40938 | 31459 | 11636 | 2705 | 566 |

APPENDIX D

Table 8

POPULATION: Beta

SAMPLE SIZE: 5

Part I Population Parameters

| | | | | | |
|----------|------|-------|-----|------|-------|
| Mean | .5 | .44 | .40 | .36 | .33 |
| STD.DEV. | .167 | .1589 | .50 | .140 | .1329 |
| Index | (1) | (2) | (3) | (4) | (5) |

Part II Comparison of Distribution Frequencies

| Inter- val | < $\mu-3\sigma$ | $\mu-3\sigma$ | $\mu-2\sigma$ | $\mu-\sigma$ | $\mu+\sigma$ | $\mu+2\sigma$ | $\mu+3\sigma$ | > $\mu+3\sigma$ |
|---------------|--------------------|---------------|---------------|--------------|--------------|---------------|---------------|--------------------|
| N(0,1) | 74 | 524 | 3399 | 8499 | 8499 | 3399 | 524 | 74 |
| Beta(0,1) | | | | | | | | |
| (1)* | 0 | 411 | 3879 | 8062 | 8333 | 3896 | 419 | 0 |
| (2)* | 0 | 298 | 3894 | 8414 | 8146 | 3670 | 575 | 3 |
| (3)* | 0 | 194 | 3890 | 8739 | 7987 | 3515 | 660 | 15 |
| (4)* | 0 | 151 | 3942 | 8919 | 7849 | 3445 | 656 | 38 |
| (5)* | 0 | 100 | 3919 | 9111 | 7736 | 3382 | 696 | 56 |

APPENDIX D

Table 9

POPULATION: Beta

SAMPLE SIZE: 10

Part I Population Parameters

| | | | | | |
|----------|------|------|------|-------|------|
| Mean | .5 | .44 | .40 | .36 | .33 |
| STD.DEV. | .167 | .157 | .148 | .1397 | .132 |
| Index | (1) | (2) | (3) | (4) | (5) |

Part II Comparison of Distribution Frequencies

| Inter- val | < $\mu-3\sigma$ | $\mu-3\sigma$ | $\mu-2\sigma$ | $\mu-\sigma$ | $\mu+\sigma$ | $\mu+2\sigma$ | $\mu+3\sigma$ | > $\mu+3\sigma$ |
|---------------|--------------------|---------------|---------------|--------------|--------------|---------------|---------------|--------------------|
| N(0,1) | 149 | 1049 | 6799 | 16999 | 16999 | 6799 | 1049 | 149 |
| Beta(0,1) | | | | | | | | |
| Index (1)* | 0 | 802 | 7637 | 16467 | 16467 | 7726 | 935 | 0 |
| (2)* | 0 | 629 | 7841 | 16813 | 16123 | 7418 | 1164 | 10 |
| (3)* | 0 | 481 | 7796 | 14386 | 15766 | 7139 | 1387 | 45 |
| (4)* | 0 | 325 | 7879 | 17801 | 15558 | 6916 | 1457 | 64 |
| (5)* | 0 | 261 | 7789 | 18124 | 15378 | 6931 | 1396 | 121 |

APPENDIX D

Table 10

POPULATION: Beta

SAMPLE SIZE: 15

Part I

Population Parameters

| | | | | | |
|----------|------|-------|-------|-------|-------|
| Mean | .5 | .44 | .4 | .36 | .33 |
| STD.DEV. | .166 | .1577 | .1477 | .1385 | .1308 |
| Index | (1) | (2) | (3) | (4) | (5) |

Part II

Comparisons of Distribution Frequencies

| Inter- val | < $\mu-3\sigma$ | $\mu-3\sigma$ | $\mu-2\sigma$ | $\mu-\sigma$ | $\mu+\sigma$ | $\mu+2\sigma$ | $\mu+3\sigma$ | > $\mu+3\sigma$ |
|---------------|--------------------|---------------|---------------|--------------|--------------|---------------|---------------|--------------------|
| N(0,1) | 224 | 1574 | 10199 | 25499 | 25499 | 10199 | 1574 | 224 |
| Beta(0,1) | | | | | | | | |
| Index (1)* | 0 | 1225 | 11574 | 24441 | 24621 | 11812 | 1327 | 0 |
| (2)* | 0 | 931 | 11741 | 25404 | 23774 | 11407 | 1727 | 16 |
| (3)* | 0 | 683 | 11820 | 26111 | 23470 | 10762 | 2105 | 49 |
| (4)* | 0 | 530 | 11927 | 26398 | 23346 | 10494 | 2189 | 116 |
| (5)* | 0 | 429 | 11841 | 26916 | 23037 | 10283 | 2275 | 176 |

APPENDIX D

Table 11

POPULATION: Beta

SAMPLE SIZE: 20

Part I Population Parameters

| | | | | | |
|----------|------|------|-------|------|-------|
| Mean | .5 | .44 | .40 | .36 | .33 |
| STD.DEV. | .167 | .156 | .1469 | .138 | .1297 |
| Index | (1) | (2) | (3) | (4) | (5) |

Part II Comparison of Distribution Frequencies

| Inter-vals | < $\mu-3\sigma$ | $\mu-3\sigma$ | $\mu-2\sigma$ | $\mu-\sigma$ | $\mu+\sigma$ | $\mu+2\sigma$ | $\mu+3\sigma$ | > $\mu+3\sigma$ |
|---------------|--------------------|---------------|---------------|--------------|--------------|---------------|---------------|--------------------|
| N(0,1) | 299 | 2099 | 13599 | 33999 | 33999 | 13599 | 2099 | 299 |
| Beta(0,1) | | | | | | | | |
| Index (1)* | 0 | 1641 | 15458 | 32592 | 3271 | 15798 | 1780 | 0 |
| (2)* | 0 | 1252 | 15714 | 33539 | 32161 | 14858 | 2447 | 29 |
| (3)* | 0 | 970 | 15740 | 34596 | 31365 | 14505 | 2721 | 103 |
| (4)* | 0 | 766 | 15774 | 35284 | 31087 | 13905 | 3005 | 179 |
| (5)* | 0 | 586 | 15896 | 35825 | 30499 | 13853 | 3094 | 247 |

APPENDIX E

Table 12

POPULATION: Beta

SAMPLE SIZE: 5 (Fixed Mean, Difference Variance)

Part I Population Parameters

| | | | | | |
|----------|-------|------|-------|------|-------|
| Mean | .5 | .5 | .5 | .5 | .5 |
| Variance | .1036 | .022 | .0195 | .013 | .0108 |
| Index | (1) | (2) | (3) | (4) | (5) |

Part II Comparison of Distribution Frequencies

| Inter- val | < $\mu-3\sigma$ | $\mu-3\sigma$ | $\mu-2\sigma$ | $\mu-\sigma$ | $\mu+\sigma$ | $\mu+2\sigma$ | $\mu+3\sigma$ | > $\mu+3\sigma$ |
|---------------|--------------------|---------------|---------------|--------------|--------------|---------------|---------------|--------------------|
| N(0,1) | 74 | 524 | 3399 | 8499 | 8499 | 3399 | 524 | 74 |
| Beta(0,1) | | | | | | | | |
| Index (1)* | 0 | 166 | 4394 | 7941 | 7764 | 4572 | 165 | 0 |
| (2)* | 0 | 397 | 3908 | 8075 | 8336 | 3846 | 436 | 0 |
| (3)* | 3 | 430 | 3584 | 8573 | 8456 | 3659 | 493 | 2 |
| (4)* | 3 | 439 | 3573 | 8399 | 8492 | 3597 | 486 | 11 |
| (5)* | 9 | 431 | 3456 | 8496 | 8575 | 3581 | 439 | 11 |

APPENDIX E

Table 13

POPULATION: Beta

SAMPLE SIZE: 10 (Fixed Mean, Difference Variance)

Part I Population Parameters

| | | | | | |
|----------|------|------|-------|------|-------|
| Mean | .5 | .5 | .5 | .5 | .5 |
| Variance | .036 | .022 | .0195 | .013 | .0108 |
| Index | (1) | (2) | (3) | (4) | (5) |

Part II Comparison of Distribution Frequencies

| Inter- vals | < $\mu-3\sigma$ | $\mu-3\sigma$ | $\mu-2\sigma$ | $\mu-\sigma$ | $\mu+\sigma$ | $\mu+2\sigma$ | $\mu+3\sigma$ | > $\mu+3\sigma$ |
|----------------|--------------------|---------------|---------------|--------------|--------------|---------------|---------------|--------------------|
| N(0,1) | 149 | 1049 | 6799 | 16999 | 16999 | 6799 | 1049 | 149 |
| Beta(0,1) | | | | | | | | |
| Index (1)* | 0 | 399 | 8788 | 15650 | 15758 | 8963 | 442 | 0 |
| (2)* | 0 | 838 | 7653 | 16251 | 16653 | 7811 | 894 | 0 |
| (3)* | 8 | 861 | 7361 | 16598 | 16669 | 7534 | 959 | 11 |
| (4)* | 15 | 946 | 7026 | 16749 | 16940 | 7318 | 985 | 21 |
| (5) | 12 | 919 | 6985 | 16834 | 16964 | 7226 | 1033 | 27 |

APPENDIX F

Table 14

POPULATION: Erlang

POPULATION MEAN: 1.33

| Degrees of Freedom | VALUES OF $1-\alpha$ | | | | | | | |
|--------------------|----------------------|--------|--------|--------|--------|------|------|------|
| | .2 | .5 | .8 | .9 | .95 | .98 | .99 | .999 |
| 4 | .7416* | .9660* | .9960* | .9982* | .9996* | 1.0* | 1.0* | 1.0 |
| 9 | .9586* | 1.0* | 1.0* | 1.0* | 1.0* | 1.0* | 1.0* | 1.0 |
| 14 | .9946* | 1.0* | 1.0* | 1.0* | 1.0* | 1.0* | 1.0* | 1.0 |
| 19 | .9996* | 1.0* | 1.0* | 1.0* | 1.0* | 1.0* | 1.0* | 1.0 |

APPENDIX F

Table 15

POPULATION: Erlang

POPULATION MEAN: 1.667

| Degrees of Freedom | VALUES OF $1-\alpha$ | | | | | | | |
|--------------------------|----------------------|--------|--------|--------|--------|------|------|------|
| | .2 | .5 | .8 | .9 | .95 | .98 | .99 | .999 |
| 4 | .7480* | .9708* | .9980* | .9998* | .9998* | 1.0* | 1.0* | 1.0 |
| 9 | .9650* | .998* | 1.0* | 1.0* | 1.0* | 1.0* | 1.0* | 1.0 |
| 14 | .9952* | 1.0* | 1.0* | 1.0* | 1.0* | 1.0* | 1.0* | 1.0 |
| 19 | .9998* | 1.0* | 1.0* | 1.0* | 1.0* | 1.0* | 1.0* | 1.0 |

APPENDIX F

Table 16

POPULATION: Erlang

POPULATION MEAN: 2.0

| Degrees of Freedom | VALUES OF $1-\alpha$ | | | | | | | |
|--------------------|----------------------|--------|--------|--------|--------|------|------|------|
| | .2 | .5 | .8 | .9 | .95 | .98 | .99 | .999 |
| 4 | .7466* | .9708* | .9966* | .9994* | .9998* | 1.0* | 1.0* | 1.0 |
| 9 | .9608 | .999* | 1.0* | 1.0* | 1.0* | 1.0* | 1.0* | 1.0 |
| 14 | .9958* | 1.0* | 1.0* | 1.0* | 1.0* | 1.0* | 1.0* | 1.0* |
| 19 | 1.0* | 1.0* | 1.0* | 1.0* | 1.0* | 1.0* | 1.0* | 1.0 |

APPENDIX F

Table 17

POPULATION: Erlang

POPULATION MEAN: 2.33

| Degrees of Freedom | VALUES OF $1-\alpha$ | | | | | | | |
|--------------------|----------------------|--------|--------|--------|--------|------|------|------|
| | .2 | .5 | .8 | .9 | .95 | .98 | .99 | .999 |
| 4 | .7394* | .9732* | .9972* | .9994* | .9998* | 1.0* | 1.0* | 1.0 |
| 9 | .9640* | .999* | 1.0* | 1.0* | 1.0* | 1.0* | 1.0* | 1.0 |
| 14 | .9970* | 1.0* | 1.0* | 1.0* | 1.0* | 1.0* | 1.0* | 1.0 |
| 19 | 1.0* | 1.0* | 1.0* | 1.0* | 1.0* | 1.0* | 1.0* | 1.0 |

APPENDIX F

Table 18

POPULATION: Erlang

POPULATION MEAN: 2.667

| Degrees of Freedom | VALUES OF $1-\alpha$ | | | | | | | |
|--------------------------|----------------------|--------|--------|-------|------|------|------|------|
| | .2 | .5 | .8 | .9 | .95 | .98 | .99 | .999 |
| 4 | .754* | .9750* | .9982* | .998* | 1.0* | 1.0* | 1.0* | 1.0 |
| 9 | .9656* | .999* | 1.0* | 1.0* | 1.0* | 1.0* | 1.0* | 1.0 |
| 14 | .9962* | 1.0* | 1.0* | 1.0* | 1.0* | 1.0* | 1.0* | 1.0 |
| 19 | 1.0* | 1.0* | 1.0* | 1.0* | 1.0* | 1.0* | 1.0* | 1.0 |

APPENDIX G

Table 19

POPULATION: BETA

POPULATION MEAN: .5

| Degrees of Freedom | ACTUAL SIGNIFICANCE LEVELS | | | | | | | |
|--------------------------|----------------------------|-------|------|------|------|------|------|------|
| | .8 | .5 | .2 | .1 | .05 | .02 | .01 | .001 |
| 4 | .793* | .485* | .196 | .099 | .051 | .020 | .011 | .002 |
| 9 | .795* | .497 | .199 | .099 | .051 | .023 | .014 | .002 |
| 14 | .807* | .498 | .196 | .095 | .050 | .040 | .010 | .001 |
| 19 | .809* | .501 | .199 | .102 | .051 | .021 | .01 | .001 |

APPENDIX G

Table 20

POPULATION: Beta

POPULATION MEAN: .44

| Degrees of Freedom | ACTUAL SIGNIFICANCE LEVELS | | | | | | | |
|--------------------------|----------------------------|-------|-------|-------|-------|------|------|------|
| | .8 | .5 | .2 | .1 | .05 | .02 | .01 | .001 |
| 4 | .793* | .480* | .190* | .099 | .050 | .021 | .001 | .001 |
| 9 | .805* | .053 | .200 | .102 | .050 | .021 | .011 | .001 |
| 14 | .799 | .489* | .193* | .098 | .050 | .041 | .012 | .001 |
| 19 | .805* | .509* | .200 | .109* | .058* | .023 | .02 | .001 |

APPENDIX G

Table 21

POPULATION: Beta

POPULATION MEAN: .40

| Degrees of Freedom | ACTUAL SIGNIFICANCE LEVELS | | | | | | | |
|--------------------------|----------------------------|-------|-------|------|------|------|------|------|
| | .8 | .5 | .2 | .1 | .05 | .02 | .01 | .001 |
| 4 | .793* | .488* | .192* | .096 | .050 | .020 | .010 | .001 |
| 9 | .802 | .491* | .192* | .096 | .048 | .021 | .010 | .001 |
| 14 | .803* | .503 | .196 | .101 | .053 | .043 | .011 | .002 |
| 19 | .791* | .494* | .189 | .094 | .046 | .018 | .01 | .002 |

APPENDIX G

Table 22

POPULATION: Beta

POPULATION MEAN: .36

| Degrees of Freedom | ACTUAL SIGNIFICANCE LEVELS | | | | | | | |
|--------------------------|----------------------------|-------|------|------|------|------|------|------|
| | .8 | .5 | .2 | .1 | .05 | .02 | .01 | .001 |
| 4 | .798 | .492* | .204 | .098 | .053 | .020 | .010 | .001 |
| 9 | .793* | .494* | .194 | .102 | .054 | .021 | .012 | .001 |
| 14 | .795* | .507* | .204 | .100 | .051 | .043 | .011 | .002 |
| 19 | .803* | .501 | .196 | .094 | .050 | .022 | .01 | .001 |

APPENDIX G

Table 23

POPULATION: Beta

POPULATION MEAN: .33

| Degrees of Freedom | ACTUAL SIGNIFICANCE LEVELS | | | | | | | |
|--------------------------|----------------------------|-------|-------|-------|-------|-------|-------|-------|
| | .8 | .5 | .2 | .1 | .05 | .02 | .01 | .001 |
| 4 | .801 | .504 | .205 | .107* | .061* | .023* | .012* | .003* |
| 9 | .793* | .504 | .200 | .101 | .052 | .023 | .011 | .001 |
| 14 | .796* | .507* | .209* | .106 | .052 | .046 | .013 | .002 |
| 19 | .794* | .493* | .193* | .103 | .054 | .023 | .02 | .001 |

APPENDIX H

Table 24

POPULATION: Beta (Fixed Mean- Different Variance)
 POPULATION MEAN: .5
 POPULATION VARIANCE: .036

| Degrees of Freedom | ACTUAL SIGNIFICANCE LEVELS | | | | | | | |
|--------------------------|----------------------------|--------|--------|--------|--------|--------|--------|-------|
| | .8 | .5 | .2 | .1 | .05 | .02 | .01 | .001 |
| 4 | .7860* | .4796* | .2084* | .1160* | .0682* | .0314* | .0176* | .0012 |
| 9 | .7952* | .4870* | .1948 | .1054 | .0562* | .0244 | .0132 | .0018 |

APPENDIX H

Table 25

POPULATION: Beta (Fixed Mean-Different Variance)
 POPULATION MEAN: .5
 POPULATION VARIANCE: .022

| Degrees of Freedom | ACTUAL SIGNIFICANCE LEVELS | | | | | | | |
|--------------------|----------------------------|--------|-------|-------|-------|-------|-------|-------|
| | .8 | .5 | .2 | .1 | .05 | .02 | .01 | .001 |
| 4 | .7874* | .4842* | .2002 | .1052 | .0538 | .0238 | .0118 | .0012 |
| 9 | .8008 | .4934 | .1992 | .0998 | .0538 | .0220 | .0130 | .0012 |

APPENDIX H

Table 26

POPULATION: Beta (Fixed Mean-Different Variance)
 POPULATION MEAN: .5
 POPULATION VARIANCE: .0195

| Degrees of Freedom | ACTUAL SIGNIFICANCE LEVELS | | | | | | | |
|--------------------|----------------------------|--------|-------|-------|-------|-------|-------|-------|
| | .8 | .5 | .2 | .1 | .05 | .02 | .01 | .001 |
| 4 | .7908* | .4914* | .1948 | .1068 | .0556 | .0224 | .0102 | .0008 |
| 9 | .8012 | .5042 | .1956 | .0976 | .0486 | .0220 | .0094 | .0008 |

APPENDIX H

Table 27

POPULATION: Beta
 POPULATION MEAN: .5
 POPULATION VARIANCE: .013

| Degrees of Freedom | ACTUAL SIGNIFICANCE LEVELS | | | | | | | |
|--------------------------|----------------------------|--------|--------|--------|-------|-------|-------|-------|
| | .8 | .5 | .2 | .1 | .05 | .02 | .01 | .001 |
| 4 | .7864* | .4824* | .1868* | .0924* | .0484 | .0188 | .0084 | .0002 |
| 9 | .7910* | .4908* | .1940 | .0970 | .0492 | .0196 | .0112 | .0018 |

APPENDIX H

Table 28

POPULATION: Beta
 POPULATION MEAN: .5
 POPULATION VARIANCE: .0108

| Degrees of Freedom | ACTUAL SIGNIFICANCE LEVELS | | | | | | | |
|--------------------------|----------------------------|--------|-------|-------|-------|-------|-------|-------|
| | .8 | .5 | .2 | .1 | .05 | .02 | .01 | .001 |
| 4 | .8026* | .4906* | .2004 | .1 | .0498 | .0204 | .0104 | .0014 |
| 9 | .7910 | .5030 | .2010 | .0974 | .0464 | .0172 | .0090 | .0008 |

APPENDIX J

Instructions for the Use of Computer Program

The attached computer program was used to obtain the simulation results for the Beta distribution. The program, written in Fortran language, makes use of an IBM 360 computer. This program consists of four simulations, requires 47 minutes of execution time, and makes use of 505 K storage capacity. The program as presented in Appendix J, is self sufficient in that it does not require any external sub-routines or programs for its execution. The program contains its own random number generator with the variant seed characteristics. It enables the user to manipulate the various parameters without any reorganization of the program.

To assist users in understanding and utilizing various facets of the program, a number of comment cards are used through-out the program. In order to illustrate the techniques of varying the parameters of the Erlang distribution or the number of cycles in the simulation, or the number of samples for the distributions, the following instructions could be useful. If one consults Appendix J, page 62, he should find that parameters $B_1 = 3$ corresponds to $\lambda = 3$, and the values of K_1 and K_2 represent the values of parameter K in the Erlang distribution. In order to obtain five different Erlang distributions in each cycle of each simulation (as illustrated in Table 2), one would set $K_1 = 4$, $K_2 = 3$ and make use of the Do loop 777. Thus in order to change the number of cycles to 3, one would simply replace Do 777 IB=1,5 with Do 777 IB=1,3.

This program is designed to furnish 4 different sample sizes. This is accomplished by the first Do loop on page 62; i.e., Do 778 IN=1,4. The sample size is determined by the value of the increment in statement, $MR = MR + 5$. If four samples of sample size 2, 4, 6, and 8 are required, one would simply change the statement $MR = MR + 2$. If only two samples of 5000 each are desired, then one would replace Do 778 IN = 1,4 by Do 778 IN = 1,2. The number of samples in each simulation are determined by the Do loop "Do 1000 II = 1,50. As is apparent from the dimensions of GAMMA1 and GAMMA2, the program for given values of K_1 and K_2 generates 100 samples of size MR which are Beta distributed. It calculates the new t statistic, compares the absolute values of this statistic with the critical values, and stores the beta variate in location called "STOR". Utilizing a different seed, the entire process is repeated 50 times, thus yielding a total of 5000 samples of size MR. After the generation of 5000 samples which are located in "STOR", the distribution frequency comparisons are performed; and the desired results are provided as indicated in Appendix J. The values of parameters are then incremented by the Do loop 778, and the entire process is repeated until 5 cycles are completed for the value of sample size. At the end of Simulation I, the sample size is incremented, and the entire process is repeated.

A sample of the results of one simulation are furnished in Appendix J. It may be recalled that each simulation

consists of five cycles; for each cycle, the program furnishes the following information as shown in Appendix J:

1. Transformed Beta frequency distribution denoted by (1) .
2. $N(0,1)$ frequency distribution denoted by (2) .
3. Sample size denoted by (3) .
4. Distribution mean denoted by (4) .
5. The actual levels of significance denoted by (5) .
6. The observed levels of significance denoted by (6) .
7. The $\chi^2(1)$ statistic for each level of significance
.95
denoted by (7) .

At the end of the simulation, a summary of the results is furnished which contains the actual alpha values, the observed alpha values for each of the five cycles, $\chi^2_{.95}$ values for one degree of freedom, and the observed $\chi^2(1)$ statistics for each significance level. The computer program for the Gamma distribution also utilizes the same techniques. This program is furnished in Appendix J.


```

REAL*8 GAMMA1(100,20), GAMMA2(100,20), GAMMA3(100,20), RIZWAN(100,2)/RIZWAN(100,2)
*200*0.0/TOBS2(100).A,X
COMMON /SMIN,SMAX,XM,XL,ILA1,ILA2,ILA3,ILA4,ILA5,ILA6,ILA7,ILA8,ILA9,ILA10,ILA11,ILA12,ILA13,ILA14,ILA15,ILA16,ILA17,ILA18,ILA19,ILA20,ILA21,ILA22,ILA23,ILA24,ILA25,ILA26,ILA27,ILA28,ILA29,ILA30,ILA31,ILA32,ILA33,ILA34,ILA35,ILA36,ILA37,ILA38,ILA39,ILA40,ILA41,ILA42,ILA43,ILA44,ILA45,ILA46,ILA47,ILA48,ILA49,ILA50,ILA51,ILA52,ILA53,ILA54,ILA55,ILA56,ILA57,ILA58,ILA59,ILA60,ILA61,ILA62,ILA63,ILA64,ILA65,ILA66,ILA67,ILA68,ILA69,ILA70,ILA71,ILA72,ILA73,ILA74,ILA75,ILA76,ILA77,ILA78,ILA79,ILA80,ILA81,ILA82,ILA83,ILA84,ILA85,ILA86,ILA87,ILA88,ILA89,ILA90,ILA91,ILA92,ILA93,ILA94,ILA95,ILA96,ILA97,ILA98,ILA99,ILA100,ILA101,ILA102,ILA103,ILA104,ILA105,ILA106,ILA107,ILA108,ILA109,ILA110,ILA111,ILA112,ILA113,ILA114,ILA115,ILA116,ILA117,ILA118,ILA119,ILA120,ILA121,ILA122,ILA123,ILA124,ILA125,ILA126,ILA127,ILA128,ILA129,ILA130,ILA131,ILA132,ILA133,ILA134,ILA135,ILA136,ILA137,ILA138,ILA139,ILA140,ILA141,ILA142,ILA143,ILA144,ILA145,ILA146,ILA147,ILA148,ILA149,ILA150,ILA151,ILA152,ILA153,ILA154,ILA155,ILA156,ILA157,ILA158,ILA159,ILA160,ILA161,ILA162,ILA163,ILA164,ILA165,ILA166,ILA167,ILA168,ILA169,ILA170,ILA171,ILA172,ILA173,ILA174,ILA175,ILA176,ILA177,ILA178,ILA179,ILA180,ILA181,ILA182,ILA183,ILA184,ILA185,ILA186,ILA187,ILA188,ILA189,ILA190,ILA191,ILA192,ILA193,ILA194,ILA195,ILA196,ILA197,ILA198,ILA199,ILA200,ILA201,ILA202,ILA203,ILA204,ILA205,ILA206,ILA207,ILA208,ILA209,ILA210,ILA211,ILA212,ILA213,ILA214,ILA215,ILA216,ILA217,ILA218,ILA219,ILA220,ILA221,ILA222,ILA223,ILA224,ILA225,ILA226,ILA227,ILA228,ILA229,ILA230,ILA231,ILA232,ILA233,ILA234,ILA235,ILA236,ILA237,ILA238,ILA239,ILA240,ILA241,ILA242,ILA243,ILA244,ILA245,ILA246,ILA247,ILA248,ILA249,ILA250,ILA251,ILA252,ILA253,ILA254,ILA255,ILA256,ILA257,ILA258,ILA259,ILA260,ILA261,ILA262,ILA263,ILA264,ILA265,ILA266,ILA267,ILA268,ILA269,ILA270,ILA271,ILA272,ILA273,ILA274,ILA275,ILA276,ILA277,ILA278,ILA279,ILA280,ILA281,ILA282,ILA283,ILA284,ILA285,ILA286,ILA287,ILA288,ILA289,ILA290,ILA291,ILA292,ILA293,ILA294,ILA295,ILA296,ILA297,ILA298,ILA299,ILA300,ILA301,ILA302,ILA303,ILA304,ILA305,ILA306,ILA307,ILA308,ILA309,ILA310,ILA311,ILA312,ILA313,ILA314,ILA315,ILA316,ILA317,ILA318,ILA319,ILA320,ILA321,ILA322,ILA323,ILA324,ILA325,ILA326,ILA327,ILA328,ILA329,ILA330,ILA331,ILA332,ILA333,ILA334,ILA335,ILA336,ILA337,ILA338,ILA339,ILA340,ILA341,ILA342,ILA343,ILA344,ILA345,ILA346,ILA347,ILA348,ILA349,ILA350,ILA351,ILA352,ILA353,ILA354,ILA355,ILA356,ILA357,ILA358,ILA359,ILA360,ILA361,ILA362,ILA363,ILA364,ILA365,ILA366,ILA367,ILA368,ILA369,ILA370,ILA371,ILA372,ILA373,ILA374,ILA375,ILA376,ILA377,ILA378,ILA379,ILA380,ILA381,ILA382,ILA383,ILA384,ILA385,ILA386,ILA387,ILA388,ILA389,ILA390,ILA391,ILA392,ILA393,ILA394,ILA395,ILA396,ILA397,ILA398,ILA399,ILA400,ILA401,ILA402,ILA403,ILA404,ILA405,ILA406,ILA407,ILA408,ILA409,ILA410,ILA411,ILA412,ILA413,ILA414,ILA415,ILA416,ILA417,ILA418,ILA419,ILA420,ILA421,ILA422,ILA423,ILA424,ILA425,ILA426,ILA427,ILA428,ILA429,ILA430,ILA431,ILA432,ILA433,ILA434,ILA435,ILA436,ILA437,ILA438,ILA439,ILA440,ILA441,ILA442,ILA443,ILA444,ILA445,ILA446,ILA447,ILA448,ILA449,ILA450,ILA451,ILA452,ILA453,ILA454,ILA455,ILA456,ILA457,ILA458,ILA459,ILA460,ILA461,ILA462,ILA463,ILA464,ILA465,ILA466,ILA467,ILA468,ILA469,ILA470,ILA471,ILA472,ILA473,ILA474,ILA475,ILA476,ILA477,ILA478,ILA479,ILA480,ILA481,ILA482,ILA483,ILA484,ILA485,ILA486,ILA487,ILA488,ILA489,ILA490,ILA491,ILA492,ILA493,ILA494,ILA495,ILA496,ILA497,ILA498,ILA499,ILA500,ILA501,ILA502,ILA503,ILA504,ILA505,ILA506,ILA507,ILA508,ILA509,ILA510,ILA511,ILA512,ILA513,ILA514,ILA515,ILA516,ILA517,ILA518,ILA519,ILA520,ILA521,ILA522,ILA523,ILA524,ILA525,ILA526,ILA527,ILA528,ILA529,ILA530,ILA531,ILA532,ILA533,ILA534,ILA535,ILA536,ILA537,ILA538,ILA539,ILA540,ILA541,ILA542,ILA543,ILA544,ILA545,ILA546,ILA547,ILA548,ILA549,ILA550,ILA551,ILA552,ILA553,ILA554,ILA555,ILA556,ILA557,ILA558,ILA559,ILA560,ILA561,ILA562,ILA563,ILA564,ILA565,ILA566,ILA567,ILA568,ILA569,ILA570,ILA571,ILA572,ILA573,ILA574,ILA575,ILA576,ILA577,ILA578,ILA579,ILA580,ILA581,ILA582,ILA583,ILA584,ILA585,ILA586,ILA587,ILA588,ILA589,ILA590,ILA591,ILA592,ILA593,ILA594,ILA595,ILA596,ILA597,ILA598,ILA599,ILA600,ILA601,ILA602,ILA603,ILA604,ILA605,ILA606,ILA607,ILA608,ILA609,ILA610,ILA611,ILA612,ILA613,ILA614,ILA615,ILA616,ILA617,ILA618,ILA619,ILA620,ILA621,ILA622,ILA623,ILA624,ILA625,ILA626,ILA627,ILA628,ILA629,ILA630,ILA631,ILA632,ILA633,ILA634,ILA635,ILA636,ILA637,ILA638,ILA639,ILA640,ILA641,ILA642,ILA643,ILA644,ILA645,ILA646,ILA647,ILA648,ILA649,ILA650,ILA651,ILA652,ILA653,ILA654,ILA655,ILA656,ILA657,ILA658,ILA659,ILA660,ILA661,ILA662,ILA663,ILA664,ILA665,ILA666,ILA667,ILA668,ILA669,ILA670,ILA671,ILA672,ILA673,ILA674,ILA675,ILA676,ILA677,ILA678,ILA679,ILA680,ILA681,ILA682,ILA683,ILA684,ILA685,ILA686,ILA687,ILA688,ILA689,ILA690,ILA691,ILA692,ILA693,ILA694,ILA695,ILA696,ILA697,ILA698,ILA699,ILA700,ILA701,ILA702,ILA703,ILA704,ILA705,ILA706,ILA707,ILA708,ILA709,ILA710,ILA711,ILA712,ILA713,ILA714,ILA715,ILA716,ILA717,ILA718,ILA719,ILA720,ILA721,ILA722,ILA723,ILA724,ILA725,ILA726,ILA727,ILA728,ILA729,ILA730,ILA731,ILA732,ILA733,ILA734,ILA735,ILA736,ILA737,ILA738,ILA739,ILA740,ILA741,ILA742,ILA743,ILA744,ILA745,ILA746,ILA747,ILA748,ILA749,ILA750,ILA751,ILA752,ILA753,ILA754,ILA755,ILA756,ILA757,ILA758,ILA759,ILA760,ILA761,ILA762,ILA763,ILA764,ILA765,ILA766,ILA767,ILA768,ILA769,ILA770,ILA771,ILA772,ILA773,ILA774,ILA775,ILA776,ILA777,ILA778,ILA779,ILA780,ILA781,ILA782,ILA783,ILA784,ILA785,ILA786,ILA787,ILA788,ILA789,ILA790,ILA791,ILA792,ILA793,ILA794,ILA795,ILA796,ILA797,ILA798,ILA799,ILA800,ILA801,ILA802,ILA803,ILA804,ILA805,ILA806,ILA807,ILA808,ILA809,ILA810,ILA811,ILA812,ILA813,ILA814,ILA815,ILA816,ILA817,ILA818,ILA819,ILA820,ILA821,ILA822,ILA8
```



```

905 RIZ(S)=GAMMA2(I,J)
DO 250 I=1,100
DO 250 J=1,MR
RIZWAN(I,I)=RIZWAN(I,1)+ GAMMA2(I,J)
250 RIZWAN(I,2)=RIZWAN(I,2)+ GAMMA2(I,J)**2
DO 87 I=1,100
RIZWAN(I,2)=DSORT((RIZWAN(I,2)-RIZWAN(I,1)*RIZWAN(I,1)/MR)/(MR-1)
*)
87 RIZWAN(I,1)=RIZWAN(I,1)/MR
C THE COMPARISON OF SIGNIFICANCE LEVELS IS AS FOLLOWS
IF(MR.EQ.5) GO TO 62
IF(MR.EQ.10) GO TO 63
IF(MR.EQ.15) GO TO 64
IF(MR.EQ.20) GO TO 65
RMN=K2/3.0
62 DO 132 I=1,100
TORS2(I)=(RIZWAN(I,1)-RMN)/(RIZWAN(I,2))/MR**.5
IF(DABS(TORS2(I)).GT.0.271) ILA1=ILA1+1
IF(DABS(TORS2(I)).GT.0.271) ILA2=ILA2+1
IF(DABS(TORS2(I)).GT.0.741) ILA2A=ILA2A+1
IF(DABS(TORS2(I)).GT.0.741) ILA3=ILA3+1
IF(DABS(TORS2(I)).GT.1.533) ILA3A=ILA3A+1
IF(DABS(TORS2(I)).GT.1.533) ILA4=ILA4+1
IF(DABS(TORS2(I)).GT.2.132) ILA4A=ILA4A+1
IF(DABS(TORS2(I)).GT.2.132) ILA5=ILA5+1
IF(DABS(TORS2(I)).GT.2.776) ILA5A=ILA5A+1
IF(DABS(TORS2(I)).GT.3.747) ILA6=ILA6+1
IF(DABS(TORS2(I)).GT.3.747) ILA7=ILA7+1
IF(DABS(TORS2(I)).GT.4.604) ILA7A=ILA7A+1
IF(DABS(TORS2(I)).GT.4.604) ILA8=ILA8+1
IF(DABS(TORS2(I)).GT.8.610) ILA8A=ILA8A+1
132 CONTINUE
RMN=K2/3.0
63 DO 133 I=1,100
TORS2(I)=(RIZWAN(I,1)-RMN)/(RIZWAN(I,2))/MR**.5
IF(DABS(TORS2(I)).GT.0.261) ILA1=ILA1+1
IF(DABS(TORS2(I)).GT.0.261) ILA2=ILA2+1
IF(DABS(TORS2(I)).GT.0.703) ILA2A=ILA2A+1
IF(DABS(TORS2(I)).GT.0.703) ILA3=ILA3+1
IF(DABS(TORS2(I)).GT.1.383) ILA3A=ILA3A+1
IF(DABS(TORS2(I)).GT.1.383) ILA4=ILA4+1
IF(DABS(TORS2(I)).GT.1.833) ILA4A=ILA4A+1
IF(DABS(TORS2(I)).GT.1.833) ILA5=ILA5+1
IF(DABS(TORS2(I)).GT.2.262) ILA5A=ILA5A+1

```



```

778 WRITE(6,604)DA
    CONTINUE
    WRITE(6,7001)
7001 FORMAT(IH1,20X,'END OF JOB')
    STOP
    END
C*****
R1702890
R1702900
R1702910
R1702920
R1702930
R1702940
R1702950

```

```

SURROUTINE CLEAN
COMMON (SMIN,SMAX,XM,XL,ILA1,ILA1A,ILA2,ILA2A,ILA3,ILA3A,ILA4,ILA4A,
*A,ILA5,ILA5A,ILA6,ILA6A,ILA7,ILA7A,ILA8,ILA8A,S)
SMIN=0
SMAX=0
XM=0
XL=0
ILA1=0
ILA2=0
ILA3=0
ILA4=0
ILA5=0
ILA6=0
ILA7=0
ILA8=0
S=0
ILA1A=0
ILA2A=0
ILA3A=0
ILA4A=0
ILA5A=0
ILA6A=0
ILA7A=0
ILA8A=0
RETURN
END
C*****
C*****
C*****
R1702960
R1702970
R1702980
R1702990
R1703000
R1703010
R1703020
R1703030
R1703040
R1703050
R1703060
R1703070
R1703080
R1703090
R1703100
R1703110
R1703120
R1703130
R1703140
R1703150
R1703160
R1703170
R1703180
R1703190
R1703200
R1703210
R1703220
R1703230
R1703240

```

```

FUNCTION XBAR(X,N)
DIMENSION X(1)
SUMX=0
DO 100 I=1,N
SUMX=SUMX+X(I)
XBAR = SUMX/N
RETURN
END
100
R1703250
R1703260
R1703270
R1703280
R1703290
R1703300
R1703310
R1703320

```


C*****

RI703330

```
100
      FUNCTION STDDVN(X,N)
      DIMENSION X(1)
      SUMX=0.
      SUMX2=0.
      DO 100 I=1,N
      SUMX=SUMX+X(I)
      SUMX2=SUMX2+X(I)*X(I)
      STDDVN=SQRT((SUMX2-SUMX*SUMX/N)/(N-1))
      RETURN
      END
```

RI703340
RI703350
RI703360
RI703370
RI703380
RI703390
RI703400
RI703410
RI703420
RI703430

COMPUTER PROGRAM FOR BETA DISTRIBUTION

```

REAL*8 GAMMA1(100,20), GAMMA2(100,20), GAMMA3(100,20), MATRIX(100,20)
*4*0.0/200*0.0/3*0.0/
COMMON(SMIN,SMAX,XM,XL,ICT,ICTA,ICT1,ICT2,ICT3,ICT4,ICT5,ICT6,ICT7,ICT8,ICT9,ICT10,ICT11,ICT12,ICT13,ICT14,ICT15,ICT16,ICT17,ICT18,ICT19,ICT20)
*6*ICTA1,ICTA2,ICTA3,ICTA4,ICTA5,ICTA6,S1
INTEGER ACR(50), IPT(50,2)/100*0/, IM(50)/50*0/, IBLK/2H /, SYM/2H
**//ACRA(100), SYMA/1H*//, INTVAL(8)/8*0/, S
INTEGER GR1,GR2,GR3,GTGR3,GL1,GL2,GL3,GTGL3,MR
DIMENSION STOR(100000), D(40), DA(40)
B1=3.
K=0
K2=0
MR=0
K1=4
IX=53693
DO LOOP FOR VARIOUS SAMPLE SIZES
C THIS PROGRAMME UTILIZES FOUR SAMPLE SIZES: 5,10,15,20
DO 778 IN=1,4
  K2=3
  MR=MR+5
  NN=0
  C DO LOOP FOR VARIOUS VALUES OF THE PARAMETERS IN EACH CYCLE
  DO 777 IB=1,5
    K2=K2+1
    MMR=MR#5000
    CD=(1.0*K1)/(K1+K2)
    DO 1000 II=1,50
      DO 907 IIA=1,50
        IM(IIA)=0
        C GENERATION OF FIRST ERLANG DISTRIBUTION
        DO 10 I=1,100
          DO 10 J=1,MR
            TR=0.0
            DO 11 IK=1,K1
              IY=IX#65535
              IF(IY) 5,6,6
              IY=IY+2147483647+1
              YFL=IY
              YFL=YFL*.4656613E-9
              IX=IY
              TR=TR+ALOG(YFL)
              X=(-1.0/81)*(TR)
              IF(X*LT.XMAX) XMA=X
              IF(X*GT.XLA) XLA=X
              GAMMA1(I,J)=X
            10 GENERATION OF SECOND ERLANG DISTRIBUTION
            YFL=0.0
            DO 13 I=1,100

```



```

DO 13 J=1,MR
TR=0.0
DO 12 JJ=1,K2
IX#65539
IF(IY) 7,8
IY=IY+2147483647+1
YFL=IY
YFL=YFL*.4656613E-9
IX=IY
TR=TR+ALOG(YFL)
X=(-1.0/R1)*(TR)
IF(X.LT.XL) XL=X
IF(X.GT.XM) XM=X
12
13 THE GENERATION OF BETA DISTRIBUTION IS AS FOLLOWS
DO 15 I=1,100
GAMMA2(I,J)=X
GAMMA3(I,J)=GAMMA1(I,J)+GAMMA2(I,J)
15
9050 MATRIX(I,J)=GAMMA1(I,J)/GAMMA3(I,J)
DO 905 I=1,100
DO 905 J=1,MR
S=S+1
IF(MATRIX(I,J).LT.SMIN)SMIN=MATRIX(I,J)
IF(MATRIX(I,J).GT.SMAX)SMAX=MATRIX(I,J)
905
DO 250 I=1,100
DO 250 J=1,MR
MEAN(I,1)=MEAN(I,1)+MATRIX(I,J)
250
DO 87 I=1,100
MEAN(I,2)=DSORT((MEAN(I,2)-MEAN(I,1)*MEAN(I,1)/MR)/(MR-1))
87
XM=MEAN(1,1)
XL=MEAN(1,1)
C COMPARISON OF THE SIGNIFICANCE VALUES IS AS FOLLOWS
IF(MR.EQ.5) GO TO 25
IF(MR.EQ.10) GO TO 27
IF(MR.EQ.15) GO TO 28
IF(MR.EQ.20) GO TO 29
26
DO 20 I=1,100
TOBS(I)=(MEAN(I,1)-A)/(MEAN(I,2)/MR*.5)
IF(DABS(TOBS(I)).LE.0.271) ICT=ICT+1
IF(DABS(TOBS(I)).GT.0.271) ICTA=ICTA+1
IF(DABS(TOBS(I)).LE.0.741) ICT1=ICT1+1
IF(DABS(TOBS(I)).GT.0.741) ICTA1=ICTA1+1
IF(DABS(TOBS(I)).LE.1.533) ICT2=ICT2+1
IF(DABS(TOBS(I)).GT.1.533) ICTA2=ICTA2+1

```


72

R177011880
R177011890
R177011900
R177011910
R177011920
R177011930
R177011940
R177011950
R177011960
R177011970
R177011980
R177011990
R177020000
R177020010
R177020020
R177020030
R177020040
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R177020230
R177020240
R177020250
R177020260
R177020270
R177020280
R177020290
R177020300
R177020310
R177020320
R177020330
R177020340
R177020350

Y8=ICTA7/5000.
B2=5000
B2=(ICTA-.2*B2)**2/(.2*B2)
F1=(ICTA-A1*B2)**2/(A1*B2)
C1=F1+F2
F3=(ICTA1-.5*B2)**2/(.5*B2)
F4=(ICTA1-.5*B2)**2/(.5*B2)
C2=F3+F4
F5=(ICTA2-.8*B2)**2/(.8*B2)
F6=(ICTA2-.2*B2)**2/(.2*B2)
C3=F5+F6
F7=(ICTA3-.9*B2)**2/(.9*B2)
F8=(ICTA3-.1*B2)**2/(.1*B2)
C4=F7+F8
F9=(ICTA4-.95*B2)**2/(.95*B2)
F10=(ICTA4-.05*B2)**2/(.05*B2)
C5=F9+F10
F11=(ICTA5-.98*B2)**2/(.98*B2)
F12=(ICTA5-.02*B2)**2/(.02*B2)
C6=F11+F12
F13=(ICTA6-.99*B2)**2/(.99*B2)
F14=(ICTA6-.01*B2)**2/(.01*B2)
C7=F13+F14
F15=(ICTA7-.999*B2)**2/(.999*B2)
F16=(ICTA7-.001*B2)**2/(.001*B2)
C8=F15+F16
DA(NN+IB)=C1
DA(NN+IB+1)=C2
DA(NN+IB+2)=C3
DA(NN+IB+3)=C4
DA(NN+IB+4)=C5
DA(NN+IB+5)=C6
DA(NN+IB+6)=C7
DA(NN+IB+7)=C8
D(NN+IB)=Y1
D(NN+IB+1)=Y2
D(NN+IB+2)=Y3
D(NN+IB+3)=Y4
D(NN+IB+4)=Y5
D(NN+IB+5)=Y6
D(NN+IB+6)=Y7
D(NN+IB+7)=Y8
NN=NN+7
CQ1=.0958
CQ2=.4554
CQ3=1.324
CQ4=2.71
CQ5=3.84


```

100 FORMAT('O', ' GAMM2 RANDOM NUMBERS ARE AS FOLLOWS ',)
99  FORMAT('O', ' GAMM1 RANDOM NUMBERS ARE AS FOLLOWS ',)
101 FORMAT('O', ' IX VALUE = ', I5, ' YEL VALUE = ', F12.8)
130 FORMAT('H1', ' THE BETA FREQUENCY INTERVALS ARE AS FOLLOWS ',//)
131 *FORMAT('OX', ' LE M-3S ', LE M-2S ', LE M-S ', LE M+S ',
      *LE M+2S ', LE M+3S ',//)
41  *FORMAT('OX', 8I8)
60  *FORMAT('HO', ' NUMBER OF TOBS LE TCRIT AT ALPHA =0.8 ', I5, ' NUMRER
      *OF TOBS GT TCRIT ', I5,//)
31  *FORMAT('HO', ' NUMBER OF TOBS LE TCRIT AT ALPHA = 0.5 ', I5, ' NUMRER
      *OF TOBS GT TCRIT ', I5,//)
32  *FORMAT('HO', ' NUMBER OF TOBS LE TCRIT AT ALPHA =0.2 ', I5, ' NUMRER
      *OF TOBS GT TCRIT ', I5,//)
33  *FORMAT('HO', ' NUMBER OF TOBS LE TCRIT AT ALPHA =.1 ', I5, ' NUMRER
      *OF TOBS GT TCRIT ', I5,//)
34  *FORMAT('HO', ' NUMBER OF TOBS LE TCRIT AT ALPHA =.05 ', I5, ' NUMRER
      *OF TOBS GT TCRIT ', I5,//)
35  *FORMAT('HO', ' NUMBER OF TOBS LE TCRIT AT ALPHA =0.02 ', I5, ' NUMRER
      *OF TOBS GT TCRIT ', I5,//)
36  *FORMAT('HO', ' NUMBER OF TOBS LE TCRIT AT ALPHA =0.01 ', I5, ' NUMRER
      *OF TOBS GT TCRIT ', I5,//)
37  *FORMAT('HO', ' NUMBER OF TOBS LE TCRIT AT ALPHA = 0.001 ', I5, 'NUMRER
      *GT TCRIT ', I5,//)
62  *FORMAT('O', ' IF THE DISTRIBUTION WAS NORMAL THE FOLLOWING WOULD BE
      *EXPECTED ',//)
601 *FORMAT('HO', ' DISTRIBUTION: BETA ',//)
779 *FORMAT('HO', ' SAMPLE SIZE = ', I5,//)
604 *FORMAT('HO', ' THEORETICAL SAMPLE MEAN = ', F5.2,//)
771 *FORMAT('HO', ' STANDARD DEVIATION = ', F10.5,//)
772 *FORMAT('HO', ' D MEAN = ', F10.5,//)
602 *FORMAT('HO', ' TOTAL DATA POINTS = ', I10,//)
603 *FORMAT('OX', 8F12.3,//)
38  *FORMAT('OX', 8F13.3)
C*****
7009 DO 7009 I=1,100
777 TCBS(I)=0
      CONTINUE
609 WRITE(6,609) COMPARISON OF SIGNIFICANCE LEVELS IS AS FOLLOWS',//)
381 WRITE(6,381) CRITICAL VALUES ARE ',//)
      A1,A2,A3,A4,A5,A6,A7,A8
382 WRITE(6,382) EMPIRICAL VALUES ARE ',//)
      D
155 *FORMAT('HO', 'CHISQUARE CRITICAL VALUES ARE ',//)
      DA
      WRITE(6,603) DA

```



```

WRITE(6,603)CQ1,CQ2,CQ3,CQ4,CQ5,CQ6,CQ7,CQ8
WRITE(6,156)
FORMAT(IH0,'CHI SQ STATISTICS IS AS FOLLOWS',//)
*****Q*****
CONTINUE
WRITE(6,7001)
FORMAT(IH1,20X,'END OF JOB')
STOP
END
*****Q*****
C*****

```

```

RI703320
RI703330
RI703340
RI703350
RI703360
RI703370
RI703380
RI703390
RI703400
RI703410

```

```

SUBROUTINE CLEAN
COMMON CLEAN(SMIN,SMAX,XM,XL,ICT,ICTA,ICT1,ICT2,ICT3,ICT4,ICT5,ICT6,ICTA1,ICTA2,ICTA3,ICTA4,ICTA5,ICTA6,S)
*6,ICTA1,ICTA2,ICTA3,ICTA4,ICTA5,ICTA6,S)
SMIN=0
SMAX=0
XM=0
XL=0
ICT=0
ICT1=0
ICT2=0
ICT3=0
ICT4=0
ICT5=0
ICT6=0
ICT7=0
ICTA1=0
ICTA2=0
ICTA3=0
ICTA4=0
ICTA5=0
ICTA6=0
S=0
RETURN
END
*****
C*****

```

```

RI703420
RI703430
RI703440
RI703450
RI703460
RI703470
RI703480
RI703490
RI703500
RI703510
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RI703600
RI703610
RI703620
RI703630
RI703640
RI703650
RI703660
RI703670
RI703680

```

```

FUNCTION XBAR(X,N)
DIMENSION X(1)
SUMX=0
DO 100 I=1,N
SUMX=SUMX+X(I)
XBAR=SUMX/N
R5TURN
100
C*****

```

```

RI703690
RI703700
RI703710
RI703720
RI703730
RI703740
RI703750

```


APPENDIX J

Simulation 1, Cycle 1

The beta frequency intervals are as follows

LE M-3S, LE M-2S, LE M-S, LE MEW, LE M+S, LE M+2S, LE M+3>, GT M+3S

0 411 3879 8062 8333 3896 419 0 (1)

If the distribution was normal the following would be expected

74 524 3399 8499 8499 3399 524 74 (2)

Distribution: Beta

Sample Size = 5 (3)

Theoretical Sample Mean = 0.50 (4)

Standard Deviation = 0.16731

D Mean = 0.49941

Total Data Points = 25000

Actual α = 0.800 0.500 0.200 0.100 0.050 0.020 0.010 0.001 (5)

Observed α = 0.793 0.485 0.196 0.099 0.051 0.020 0.011 0.002 (6)

$\sum_{i=1}^2 (o_i - e_i)^2 = 1.531$ 4.743 0.405 0.020 0.152 0.000 0.182 1.802 (7)

Simulation 1, Cycle 2

The Beta Frequency Intervals are as follows

LE M-3S, LE M-2S, LE M-S, LE MEW, LE M+S, LE M+2S, LE M+3>, GT M+3S

0 298 3894 8414 8146 3670 575 0 (1)

If the distribution was normal the following would be expected

74 524 3399 8499 8499 3399 524 74 (2)

Distribution: Beta

Sample Size = 5 (3)

Theoretical Sample Mean = 0.50 (4)

Standard Deviation = 0.16731

D Mean = 0.44258

Total Data Points = 25000

Actual α = 0.800 0.500 0.200 0.100 0.050 0.020 0.010 0.001 (5)

Observed α = 0.793 0.480 0.190 0.099 0.050 0.021 0.011 0.001 (6)

$\sum_{i=1}^2 (o_i - e_i)^2 = 1.361$ 8.000 3.125 0.056 0.017 0.092 0.182 0.000 (7)

Simulation 1, Cycle 3

The Beta frequency intervals are as follows

LE M-3S, LE M-2S, LE M-S, LE MEW, LE M+S, LE M+2S, LE M+3>, GT M+3S

0 194 3890 8739 7987 3515 660 15 1

If the distribution was normal the following would be expected

74 524 3399 8499 8499 3399 524 74 2

Distribution: Beta

Sample Size = 5 3

Theoretical Sample Mean = 0.40 4

Standard Deviation = 0.15020

D Mean = 0.39854

Total Data Points = 25000

Actual α = 0.800 0.500 0.200 0.100 0.050 0.020 0.010 0.001 5

Observed α = 0.792 0.488 0.192 0.096 0.050 0.020 0.010 0.001 6

$\sum_{i=1}^2 (o_i-e_i)^2 = 2.000$ 2.977 2.000 0.720 0.017 0.041 0.000 0.000 7

Simulation 1, Cycle 4

The Beta frequency intervals are as follows

LE M-3S, LE M-2S, LE M-S, LE MEW, LE M+S, LE M+2S, LE M+3>, GT M+3S

0 151 3942 8919 7849 3445 656 38 (1)

If the distribution was normal the following would be expected

74 524 3399 8499 8499 3399 524 74 (2)

Distribution: Beta

Sample Size = 5 (3)

Theoretical Sample Mean = 0.36 (4)

Standard Deviation = 0.14029

D Mean = 0.36259

Total Data Points = 25000

Actual α = 0.800 0.500 0.200 0.100 0.050 0.020 0.010 0.001 (5)

Observed α = 0.798 0.492 0.204 0.098 0.053 0.020 0.010 0.001 (6)

$\sum_{i=1}^2 (o_i - e_i)^2 = 0.080$ 1.217 0.405 0.269 0.825 0.000 0.000 0.000 (7)

Simulation 1, Cycle 5

The Beta frequency intervals are as follows

LE M-3S, LE M-2S, LE M-S, LE MEW, LE M+S, LE M+2S, LE M+3>, GT M+3S

0 100 3919 9111 7736 3382 696 56 ①

If the distribution was normal the following would be expected

74 524 3399 8499 8499 3399 524 74 ②

Distribution: Beta

Sample Size = 5 ③

Theoretical Sample Mean = 0.33 ④

Standard Deviation = 0.13295

D Mean = 0.33244

Total Data Points = 25000

Actual α = 0.800 0.500 0.200 0.100 0.050 0.020 0.010 0.001 ⑤

Observed α = 0.801 0.504 0.205 0.107 0.061 0.023 0.012 0.003 ⑥

$\sum_{i=1}^2 (o_i - e_i)^2 = 0.061$ 0.353 0.781 2.569 12.737 2.612 2.020 12.813 ⑦

Consolidate Results of Simulation 1

Comparison of significance levels is as follows

Actual Alpha values are

| | | | | | | | | |
|-------|-------|-------|-------|-------|-------|-------|-------|---|
| 0.800 | 0.500 | 0.200 | 0.100 | 0.050 | 0.020 | 0.010 | 0.001 | 5 |
|-------|-------|-------|-------|-------|-------|-------|-------|---|

Empirical Alpha values are

| | | | | | | | | | |
|-------|-------|-------|-------|-------|-------|-------|-------|---|---------|
| 0.793 | 0.485 | 0.196 | 0.099 | 0.051 | 0.020 | 0.011 | 0.002 | 6 | Cycle 1 |
| 0.793 | 0.480 | 0.190 | 0.099 | 0.050 | 0.021 | 0.011 | 0.001 | 6 | Cycle 2 |
| 0.792 | 0.488 | 0.192 | 0.096 | 0.050 | 0.020 | 0.010 | 0.001 | 6 | Cycle 3 |
| 0.798 | 0.492 | 0.204 | 0.098 | 0.053 | 0.020 | 0.010 | 0.001 | 6 | Cycle 4 |
| 0.801 | 0.504 | 0.205 | 0.107 | 0.061 | 0.023 | 0.012 | 0.003 | 6 | Cycle 5 |

Chisquare Critical values are

$\chi^2_{1,.95}$

| | | | | | | | |
|-------|-------|-------|-------|-------|-------|-------|-------|
| 0.098 | 0.455 | 1.324 | 2.710 | 3.840 | 5.020 | 6.630 | 7.880 |
|-------|-------|-------|-------|-------|-------|-------|-------|

Chi Sq Statistics is as follows

| | | | | | | | | | |
|-------|-------|-------|-------|--------|-------|-------|--------|---|---------|
| 1.531 | 4.743 | 0.405 | 0.020 | 0.152 | 0.000 | 0.182 | 1.802 | 7 | Cycle 1 |
| 1.361 | 8.000 | 3.125 | 0.056 | 0.017 | 0.092 | 0.182 | 0.000 | 7 | Cycle 2 |
| 2.000 | 2.977 | 2.000 | 0.720 | 0.017 | 0.041 | 0.000 | 0.000 | 7 | Cycle 3 |
| 0.080 | 1.217 | 0.405 | 0.269 | 0.825 | 0.000 | 0.000 | 0.000 | 7 | Cycle 4 |
| 0.061 | 0.353 | 0.781 | 2.569 | 12.737 | 2.612 | 2.020 | 12.813 | 7 | Cycle 5 |

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| KEY WORDS | LINK A | | LINK B | | LINK C | |
|---|--------|----|--------|----|--------|----|
| | ROLE | WT | ROLE | WT | ROLE | WT |
| Robustness of a test | | | | | | |
| Power of the test | | | | | | |
| 'Student's' t-test | | | | | | |
| Mode and variance | | | | | | |
| Critical path scheduling | | | | | | |
| Inverse probability integral transformation | | | | | | |
| Simulation techniques | | | | | | |
| Critical values | | | | | | |
| Frequency comparison | | | | | | |
| Leptokurtic curve | | | | | | |
| Symmetric distribution | | | | | | |
| Skewed distribution | | | | | | |

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distributions.

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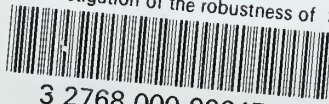
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"Student's" t-test
using Beta and Erlang
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